Gandhi Memorial College Of Education Bantalab Jammu

Goyal's

QUESTION BANK IN PHYSICS

With Model Test Papers

For Class XII

EDITION 2002

GOYAL BROTHERS PRAKASHAN

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Gandhi Memorial College Of Education Bantalab Jammu

Strictly according to the latest syllabus prescribed by the Central Board of Secondary Education, New Delhi for the Senior Secondary Examinations to be held in and ofter March 2002

Goyal's QUESTION BANK IN PHYSICS WITH MODEL TEST PAPERS

FOR CLASS XII

By
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A NOTE FROM THE PUBLISHER

The present thoroughly revised and enlarged edition of Goyal's Question Bank in Physics with Model Test Papers has been designed to serve as a help book, as per the latest syllabus and examination pattern of C.B.S.E. It provides an exposure to the type of questions that are asked in examinations with their model solutions. This Book aims at imparting an understanding and creating confidence over the subject among the students so that they are prepared for the examinations in the better way.

To aid clear preception of the new curriculum and to tackle the different range of questions, the students need comprehensive, exhaustive and yet precise material. The present volume of this book has been prepared keeping all these things in mind.

Some of the salient features of this book are :

- **A comprehensive Question Bank** of more than 4800 questions.
- Each unit contains all the **Probable Questions** that can be asked in the examination.
- Each unit consists of **Syllabus, Summary, Very Short Answer Questions, Short Answer Questions (both I & II) and Numerical Problems.**
- All questions supplemented by **Model answers** and **solutions.**
- Solved questions from previous years C.B.S.E. examination papers till 2000 have been included.
- **Three Solved Sample Papers** issued by C.B.S.E. to acquaint the students with the type of answers they are expected to write in the exam.
- A set of **10 Unsolved Model Papers** strictly according to C.B.S.E. specifications.
- **Design of Question Paper** included.
- Solved C.B.S.E. 2001 (Delhi and Outside Delhi) Papers included.
- A special note to the teachers and students regarding **how to use Model Papers.**
- **'What is a good answer?'** — Explained from a reviewer's point of view.

It is sincerely hoped that the book will prove very useful to all concerned. Comments and suggestions for further improvement are most welcome.

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SAMPLE PAPERS

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PHYSICS -CLASS XII

DESIGN OF THE QUESTION PAPERS

Time : 3 Hours **Maximum Marks : 70**

The weightages or the distribution of marks over different dimensions of the question paper shall be as follows :

1. Weightage to Learning Outcomes

S.No.	Weightage of form of questions	Marks	Percentage of marks
1.	Knowledge	20	29%
2.	Understanding	30	42%
3.	Application	20	29%
	Total	70	100

2. Weightage to Content/Subject Units :

One Paper (Theory) 3 hours 70 Marks

Unitwise Weightage

Unit		Marks
1.	Electrostatics	8
2.	Current Electricity	7
3.	Thermal and Chemical Effects of Current	8
4.	Magnetic Effect of Current	
5.	Magnetism	4
6.	Electromagnetic Induction and Alternating Current	8
7.	Electromagnetic Waves	7
8.	Wave Optics	
9.	Ray Optics and Optical Instruments	7
10.	Electrons and Photons	
11.	Atoms, Molecules and Nuclei	10
12.	Solid and Semiconductor Devices	8
13.	Universe	3

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3. Weightage to forms of Questions

S.No.	Forms of Questions	Marks for each Question	No. of Questions	Total marks	%
1.	Long Answer Type Qs.	5	3	15	21.4
2.	Short Ans. Qs. I	3	9	27	38.5
3.	Short Ans. Qs. II	2	10	20	28.6
4.	V. Short Ans. Qs.	1	8	8	11.5
	Total	—	30	70	100

Note : Although the weightage of different content areas and form of questions has been assigned, and the paper setter will adhere to the weightage but there can be little variation in distribution of marks over different units/ forms of questions in the Board examination depending upon the situation.

Note : The expected length of answers and time taken under different forms of questions would be as follows :

S.No.	Form of Questions	Expected Length	Expected Time for For Each
1.	Long Answer Type (LA)	120—150 words	12 mts.
2.	Short Answer Type (SA) I/II	40—50 words/20-30 words	8 mts. /4 mts
3.	Very Short Answer	one or two sentences	2 mts.

This is only an approximation. Through students are advised to be as near the approximation as possible the actual length, however, may vary. As the total time is calculated on the basis of the number of questions required to be answered and the lengths of their anticipated answers, it would therefore, be advisable for the candidates to budget their time properly by cutting out the superfluous lengths and be within the expected limits.

4. Scheme of Options :

(1) There will be no overall option

(2) Internal Choice (either /or type) on a very selective basis may be given in only one long answer questions testing higher mental abilities.

(3) The alternate question given by way of choice should be based on the same\ objective and the Unit. It would have the same anticipated difficulty level and length of answer.

5. Weightage to difficulty level of Questions :

S.No.	Estimated Difficulty Level	Percentage
1.	Easy	20%
2.	Average	60%
3.	Difficult	20%

A question may vary in difficulty level from individual to individual. As such the approximation in respect of each question will be made by the paper setter on the basis of general aspiration from the group as a whole taking the examination.This provision is only to make the paper balance in its weight rather than to determine the pattern of marking at any stage.

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USING THE MODEL PAPERS

The Model Paper is a useful device in the hands of teachers and learners. It broadly shows the pattern of the question papers that may appear in the actual examination. This pattern, is regulated by various policy decisions with reference to weightages to different instructional objectives, types of questions, units of a subject matter etc. represented by the design of the question paper. It also reveals the general nature of the questions, their style, their depth, their expanse etc. which also pay a significant role in influencing the performance of students. In this respect, the following suggestions could be helpful :

FOR TEACHERS

(i) Note the weightages to different elements of the question paper and prepare the students accordingly. For example, increased weightage of application of knowledge and Short Answer questions calls for greater practice in answering the questions in the context of unfamiliar situations and writing answers that are to-the-point.

(ii) Preparing a question paper similar to the Model Question Paper for a pre-examination practice (mark examination) and analysing performance.

(iii) Analysing the answer of the students in relation to the marking scheme.

(iv) Preparing smaller tests called 'Unit tests' for periodical assessment in the classroom

(v) Writing questions on improved lines as denoted by the Model Question Paper. For purposes of this, it would be desirable that :

(a) the subject matter, intended for testing , is clearly defined. In other words, the scope of the question be clearly visualised as to how short or how long it should be.

(b) once the scope has been clearly visualised the subject matter be broken into finer points, parts or sub-parts as the case may be.

(c) looking at the expected answer, a suitable specific objective or skill be chosen which could be tested through the envisaged content. The important factor is to scan the list of objectives and see which of these objectives or its specific skills can lend itself to testing through the given content. In an ideal situation the process may be just reverse, where in the objective and its specific skill intended to be tested in a unit are conceived first and the scope of the question on its content points are chosen and organised accordingly. However, depending on the situation both the process could be used.

(d) having established relevance between the chosen subject matter and the specific skills proper test situation may be devised and the wording of the question may be so done that it tests nothing beyond the intended skill (s).

(vi) Preparing a question bank on each topic covering different objectives and skills for formal and informal use in the classroom.

(vii) The personal experience so acquired can also be shared with other teachers by having an interaction and collaborative efforts on similar lines in the areas not covered in their schools.

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FOR STUDENTS

(i) Noting carefully the parameters of the Model Question Papers such as the number of long answer and short answer questions, situations contained in the questions and their styles (particularly application-oriented questions) marks assigned to different topics etc.

(ii) Answering the Model Paper and getting the answers checked. In case of any difference, asking the question to one-self,
   (a) Whether you have understood the question(s) properly ?
   (b) Was the question defective or the answer was not known to you ?

(iii) Based on your answers posing questions to the teacher and getting the doubts clarified .

(iv) Collecting or compiling a series of questions on different topics and answering them.

(v) Sharing with other classmates the questions and their answers and discussions thereon to further expand the area of awareness.

WHAT MAKES A GOOD ANSWER

Though the aim of testing remains to make questions more specific so as to entail answers of similar nature yet the answers may differ from individual to individual depending on their styles and perceptions. Each individual is a unique person and so are the answers supplied by him. This is more true in respect of long answers where students have ample freedom to supply the answers in accordance with their own thinking. As such it is difficult to say categorically as to what makes a good answer. However, some of the characteristics could be enumerated which may go a long way in making the answer more appealing :

(i) Only such subject matter or points find place in the answer which are relevant to the situation.

(ii) The answer is broken into logical sequence according to the spirit of the question as the argument demands.

(iii) Each sequence is broken into small content points or steps to have a full view of the answer for pro organization.

(iv) There is a proper linkage between the first sequence and the subsequent sequences to build pro arguments as required by the question.

(v) The answer is precise and other irrelevant details are avoided in order to have economy of time expression.

(vi) Yet the answer should be complete in all respects as demanded by the questions with reference to information, ideas, comparisons, examples, sketches, diagrams, explanations etc.

(vii) The instructions in the question paper are followed meticulously with regard to the length of the answer and its description.

(viii) The language is simple and only such words are used which convey the exact sense intended.

(ix) The common words in questions such as define, explain, list, critically examine etc., should be carefully noted alongwith their other succeeding clauses like statement, steps, causes, reasons, salient feature contributions, stresses, factors, etc which denote the expectation of the paper setter. These keys play a significant role in determining the length, complexity and logic of the answer.

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UNIT - I A

ELECTROSTATICS

CBSE SYLLABUS CONTENTS

Unit I A

Frictional electricity, charges and their conservation, Coulomb's law, electric field due to a point charge, dipole, its fields along the axis and perpendicular to the axis, concept of dielectric and dielectric constant. Force and torque experienced by a dipole in a uniform electric field, Electrostatic induction.

Unit I B

Electrostatic potential, potential due to a point charge, dipole.

Statement of Gauss's theorem - its applications to find field due to an infinite plane sheet of charge and inside a hollow conducting sphere. Conductors and insulators. Presence of free charges and bound charges inside a conductor. Capacitance, parallel plate capacitor with air/dielectric medium between the plates, series and parallel combinations of capacitors, energy of a capacitor, Van de Graff generator.

Marks weightage : 8 marks out of a total of 70.
Periods allotted : 18 out of a total of 168.

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BASIC FACTS AND FORMULAE

Frictional Electricity

We find, in early Greek writings, that *amber* (the gum that, long ago, oozed from soft wood trees over many centuries, hardened into a semitransparent solid, ranging in colour from yellow to brown) acquires the property to attract small pieces of light matter, when it is rubbed against fur. We now express this property by saying that on rubbing (that is through 'friction') amber *gets electrified* or acquires an *electric charge.*

Two Types of Electricity

It was shown, by Fay, that ebonite rod, on being rubbed against fur (or glass rod, on being rubbed against silk) *repel* each other but a charged ebonite rod (rubbed with fur) and a charged glass rod *attract* each other. We were, thus, led to the conclusions:

(i) There are two kinds of electric charge : *positive* (similar to that on a glass rod rubbed with silk) and *negative* (similar to that on an ebonite rod rubbed with fur) and

(ii) two like charges repel each other, whereas two unlike charges attract each other.

The Electric Charge

It is quite difficult to give a definition of the electric charge. This is because *'charge is better understood not by saying what it is but what it does.'* We may, however, 'define' it as follows :

The 'electric charge' is a basic and characteristic property of the elementary particles (of matter) in terms of which certain force interactions and interaction energies may be described.

Basic Properties of the Electric Charge

We may list the following as the basic properties of the electric charge :

(i) Charge is a *scalar* quantity.

(ii) There are *two, and only two* types of charges – the positive charge and the negative charge.

(iii) Charges, of the same type, *always repel* one another while charges, of the opposite kinds, *always attract* one another.

(iv) Charge is *additive* in nature. This implies that the total charge of a given system is the *algebraic sum* of all the charges present in it.

(v) Charge is *quantized.* This implies that the charge (Q), on any charged body is always an *integral multiple* of the basic or elemental unit of charge which turns out to be the charge ($|e| = 1.6 \times 10^{-19}$ C) of the electron. Thus,
$Q = ne$, where $n = 0, \pm 1, \pm 2, \pm 3, \ldots\ldots$

(vi) Charge is *conserved.* This implies that, in nature we only have a *transfer* of charge from one body to another. In other words, charge is neither created nor destroyed and the total charge of an isolated system does not change with time.

Conductors and Insulators

Matter can be classified into two broad categories : *conductors* and *insulators.*

Conductors allow electric charge to flow through them easily (i.e., they allow large scale movement of electric charge through them). Insulators on the other hand, do not let electric charge to flow through them with ease, i.e., no large scale movement of electric charge is possible through them.

Mobile Charges

In most of the situations, it is only *negative charges* in the form of *free electrons,* that move from one place to another. This is so in the case of metals. However, in electrolytes and ionised gases, both positive as well as negative charges are available as *mobile charges.*

Coulomb's law

According to *Coulomb's law* (given by the French physicist Charles Augustin de Coulomb in 1784), the (mutual) electrostatic force between two point charges q_1 and q_2 is (i) directly proportional to the product of the

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charges, i.e., $q_1\, q_2$ and (ii) inversely proportional to the square of the distance separating them. Mathematically, we write

$$\mathbf{F}_{21} = k \frac{q_1 q_2}{r^2} \hat{\mathbf{r}}_{21}$$

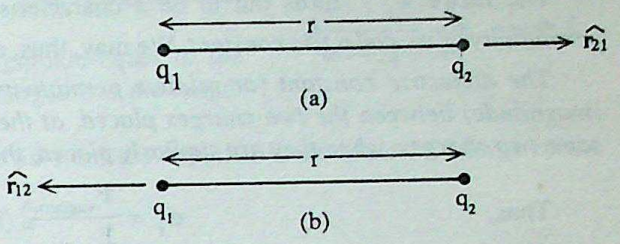
where $\hat{r}_{21}$ is a unit vector in the direction of the line drawn from q_1 to q_2

Here $\mathbf{F}_{21}$ is the force on charge q_2 due to charge q_1.

Also $\mathbf{F}_{12} = k \frac{q_1 q_2}{r^2} \hat{\mathbf{r}}_{12}$

Here $\hat{r}_{12}$ is a unit vector in the direction of the line drawn from q_2 to q_1 and $\mathbf{F}_{12}$ is the force on charge q_1 due to charge q_2. It follows that

$\mathbf{F}_{21} = -\mathbf{F}_{12}$, as expected, from *Newton's third law.*



The SI unit of charge

The SI unit of charge is the *coulomb* (C). It is a very large unit of charge and practically, one encounters charges that are in (pico coulomb) pC ($= 10^{-12}$ C), (nano coulomb) nC ($= 10^{-9}$ C) and (micro coulomb) μC ($= 10^{-6}$ C).

The Constant 'k' in SI units

In SI units, the constant 'k' is often written in the form $k = \frac{1}{4\pi\epsilon_0}$,

where ϵ_0 is known as the *permittivity* of free space. The experimentally determined value of 'k' is

$$k = \frac{1}{4\pi\epsilon_0} = 8.98755 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

We often use the value

$$k = \frac{1}{4\pi\epsilon_0} \approx 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

For usual practical calculations.

The constant $\epsilon_0 \cong 8.85 \times 10^{-12} \text{ N}^{-1} \text{ m}^{-2} \text{ C}^2$

Explicit Vector form of Coulomb's law

Let the two point charges q_1 and q_2 be located at points specified by position vectors r_1 and r_2 (with respect to some suitably chosen origin, O). We then write Coulomb's law in the explicit vector form

$$\mathbf{F}_{21} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{|\mathbf{r}_2 - \mathbf{r}_1|^3} (\mathbf{r}_2 - \mathbf{r}_1)$$

and

$$\mathbf{F}_{12} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{|\mathbf{r}_1 - \mathbf{r}_2|^3} (\mathbf{r}_1 - \mathbf{r}_2)$$

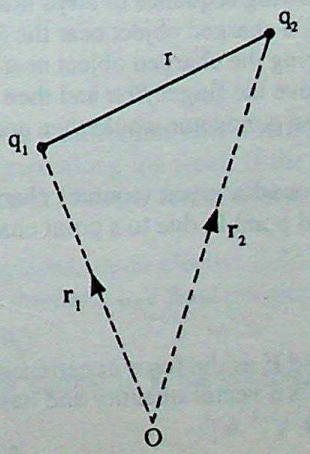
This is because

$$r = |\mathbf{r}_2 - \mathbf{r}_1| = |\mathbf{r}_1 - \mathbf{r}_2|$$

and

$$\hat{\mathbf{r}}_{21} = (\mathbf{r}_2 - \mathbf{r}_1) / |\mathbf{r}_2 - \mathbf{r}_1|$$

$$\hat{\mathbf{r}}_{12} = (\mathbf{r}_1 - \mathbf{r}_2) / |\mathbf{r}_1 - \mathbf{r}_2|$$



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The Dielectric Constant of a Medium

It is important to note that the force between two charges q_1 and q_2, kept at a given distance r apart, *decreases*, when the charges are present in a *medium* rather than in *vacuum*. The force, in case the charges are present in a medium, is written in the form

$$\mathbf{F}_{21} = \frac{1}{4\pi\epsilon_0 \epsilon_r} \frac{q_1 q_2}{r^2} \hat{\mathbf{r}}_{21}$$

The factor ϵ_r, turns out to be a characteristic property of the *medium* and is known as its *relative permittivity* or its *dielectric constant*. We may, thus, define the *dielectric constant* of a medium as follows:

The dielectric constant (or relative permittivity) of a medium may be defined as the ratio of the force (magnitude) between the two charges placed, at the given distance apart in vacuum, to the force between the same two charges, when they are similarly placed, the same distance apart, in the given medium.

Thus, $$\epsilon_r = \frac{F_{vacuum}}{F_{medium}}$$

We also often write $\epsilon_0 \epsilon_r = \epsilon$

and call ϵ as the (absolute) *permittivity* of the given medium.

It is worth noting that whereas ϵ_r is a dimensionless constant (or just a number), ϵ has the same units $(N^{-1} m^{-2} C^2)$ as those of ϵ_0.

The Principle of Superposition

If a given charge, say q is acted upon simultaneously, by electric forces from charges q_1, q_2, q_3,.....q_n, the total force on q is the vector sum of the (individual) forces that q would experience, if the individual charges were to act on q one at a time.

It follows that the (individual) force of interaction between two charges is not affected by the presence or otherwise of a third charge.

Electrostatic Induction

The phenomenon of charging of a conductor by bringing a charged object near it but not touching it, is known as electrical induction.

Salient Features of Charging by Induction

(i) The charge acquired by the uncharged object is opposite to that of the charging object.

(ii) The charging object's own charge remains unaffected.

(iii) We may use a given charged object, (repeatedly) to charge a number of other conductors by induction without any loss of its own charge.

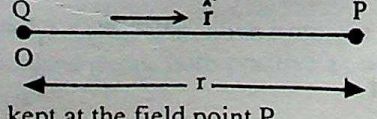
(iv) The following sequence of steps must be followed during charging by induction :
(a) Bring a charged object near the (insulated) uncharged conductor.
(b) Keeping the charged object nearby, touch the conductor with the finger (so as to 'earth' it).
(c) Remove the finger *first* and then the charged object.

The uncharged conductor would then acquire a charge opposite to that of the charging object.

Electric Field

The space around a given (source) charge is said to have an electric field due to that charge. The electric field **E** at any field point P, due to a point charge Q, placed at O, is defined by the mathematical equation,

$$\mathbf{E} = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} \hat{\mathbf{r}}$$



We may regard **E** as the force experienced by a unit positive charge kept at the field point P.

Electric field is a vector quantity and has the units newton per coulomb (NC^{-1}) or volt per metre (Vm^{-1}). Its dimensions are $ML\,T^{-3}\,A^{-1}$.

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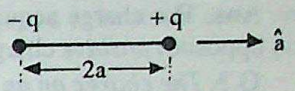
In explicit vector form, we may say that the electric field **E** at a field point P (specified by the position vector **r**) due to a point charge q, kept at a point O (specified by the position vector $\mathbf{r}_0$) is defined by

$$\mathbf{E} = \frac{1}{4\pi\epsilon_0} \frac{q}{|\mathbf{r} - \mathbf{r}_0|^3} (\mathbf{r} - \mathbf{r}_0)$$

The Electric Dipole

An electric dipole is a system of two equal and opposite point charges separated by a (small) finite distance, 2a. The distance '2a' may be regarded as the length of the dipole.



The *dipole moment* **p** of a dipole is a vector of magnitude equal to the product of the magnitude (q) of either of its constituent charges and the length (2a) of the dipole.

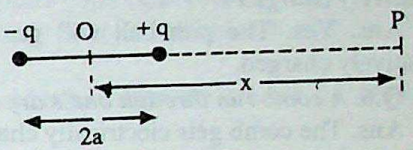
Its direction is that of a unit vector along the line drawn from the negative to the positive charge of the dipole. Thus,

$$\mathbf{p} = q(2a)\,\hat{a}$$

The Electric Field due to a Dipole

The electric field $\mathbf{E}_a$, at an axial point P, distant x, from the centre O of the dipole, is given by

$$\mathbf{E}_a = \frac{1}{4\pi\epsilon_0} \frac{2x\,p}{(x^2 - a^2)^2}$$



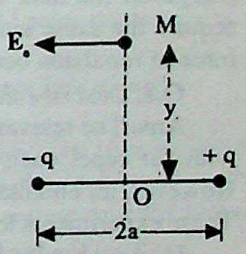
The axial field of a dipole is, thus, directed parallel to its dipole moment vector.

For a << x (*i.e.*, for a very small dipole or for a very 'far off' field point P), the axial field of the dipole is (nearly)

$$E_a \approx \frac{1}{4\pi\epsilon_0} \frac{2\mathbf{p}}{x^3}$$

For a point M, at a distance y from the centre O of the dipole, and lying on its equatorial line (*i.e.*, the line passing through the centre O of the dipole and perpendicular to its axis), the field $\mathbf{E}_e$, of a dipole is given by

$$\mathbf{E}_e = -\frac{1}{4\pi\epsilon_0} \frac{\mathbf{p}}{(y^2 + a^2)^{3/2}}$$



The equatorial field of a dipole is, thus, directed *antiparallel* to its dipole moment vector.

Force and Torque on a Dipole in an External Field

The net force acting on a dipole, of moment P, when kept in a uniform external field **E**, is zero. However, the dipole experiences a torque τ in such a field, where τ is given by

$$\tau = \mathbf{p} \times \mathbf{E}$$

Thus, $|\tau| = \tau = p\,E \sin\theta$

Because of this torque, the dipole comes into a position of stable equilibrium only when its dipole moment vector **p** becomes parallel to **E**, *i.e.*, only when the dipole gets aligned along the field. If the external field is a non-uniform one, the dipole experiences a net (translatory) force also in addition to the torque.

The P.E. of the Dipole

The charge in the potential energy of a dipole, when it is displaced, in an electric field **E**, from an initial position with its dipole moment vector **p**, making an angle θ_1 with the field, to a final position, making an angle θ_2 with the field, is given by $\Delta U = pE\,(\cos\theta_1 - \cos\theta_2)$

Taking the *zero* of potential energy at the position where **p** is normal to **E** the potential energy U at any position θ, is

$$U = -pE\cos\theta = -\mathbf{p}.\mathbf{E}$$

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SUBJECTIVE QUESTIONS ON UNIT – IA

Q.1. *A glass rod is rubbed with silk. What is the nature of charge on silk?* (1)

Ans. The silk acquires a *negative* charge.

Q.2. *An ebonite rod is rubbed against wool. What is the nature of the charge on ebonite and wool?* (1)

Ans. The charge acquired by the ebonite rod is *negative* charge while that appearing on wool is (an equal and opposite) *positive* charge.

Q.3. *The charge on an ebonite rod, rubbed against fur is – 5 μC. What is the charge; if any, on fur?* (1)

Ans. The charge appearing on fur is + 5μC.

Q.4. *A positively charged glass rod attracts a suspended pith ball. Can we conclude that the pith ball is negatively charged?*

Ans. No; not necessarily. The pith ball will get attracted by the positively charged glass rod both when it is (i) negatively charged (ii) uncharged.

Q.5. *A negatively charged ebonite rod repels a suspended pith ball. Can we conclude that the pith ball is negatively charged ?* (1)

Ans. Yes. The pith ball will get repelled by a negatively charged ebonite rod *if and only if* itself is negatively charged.

Q.6. *A comb run through one's dry hair, starts attracting small bits of paper or dry grass. Why?* (2)

Ans. The comb gets electrically charged on being run through one's dry hair. The charged comb is then able to attract small bits of paper or dry grass.

Q.7. *A charged ebonite or glass rod attracts bits of dry cork dust. However, on touching the rod, they are seen to jump violently away from it.. Explain why this happens.* (2)

Ans. The charged ebonite or glass rod attracts small bits of dry cork dust towards it by inducing an opposite charge on the near ends of the dust particles. However, once the dust particles touch the charged rod, they acquire the same kind of charge as that of the rod itself. They then get violently repelled away because of the force of repulsion between like charges.

Q.8. *Describe the experiments to show that there exist two kinds of charges in nature.* (3)

Ans. The relevant experiments were first done by Du Fay. He showed that two ebonite rods on being rubbed with fur repel each other. Two glass rods rubbed with silk also exert a force of repulsion on each other. However, an ebonite rod which has been rubbed with fur attracts a glass rod which has been rubbed with silk. These experiments lead us to the following conclusions:

(a) Two kinds of electricity exist.

(b) Bodies charged with different kinds attract each other.

(c) Bodies charged with the same kind repel each other.

Q.9. *Why do we say that repulsion alone is a surest test of electrification ?* (2)

Ans. We say that *repulsion* alone is a surest test of electrification because only a charged body can get repelled by another charged body carrying a *'like'* charge. This cannot be said in case of *attraction* because both an oppositely charged body, as well as an uncharged object can get attacted by a charged object. Hence, if a body experiences a force of attraction, from another charged body, it may very well be uncharged. However, if it gets repelled, it has to be charged (with the same kind of electricity as that on the charged object repelling it).

Q.10. *Why do metallic objects ordinarily not get charged in the same way, as an ebonite rod? How can we charge such objects ?* (2)

Ans. Metallic objects do not ordinarily get charged, on rubbing say, in the same way as an ebonite rod. This is because any charge appearing on them, leaks away to earth through the body of the person holding them. We can, however, charge them by holding them on an insulating stand.

Q.11. *Name any two basic properties of electric charge.* **(CBSE 1995 Comptt.)** (1)

Ans. Electric charge is (i) *Always conserved.* This implies that charge can neither be created nor destroyed or the total charge in the universe remains constant.

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(ii) *Quantized.* This implies that the charge q, on any object is always an *integral* multiple of the basic unit of charge which is the charge (e) on the electron. Thus $q = ne$, where $n = 0, \pm 1, \pm 2, \pm 3, ...$

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Q.12. *Can a body have a charge of* 0.8×10^{-19} C ? (1)

Ans. No. This charge is $\frac{1}{2}$ of the charge on the electron. However, since any charge must always be an integral multiple of the charge on the electron. We can say that the body cannot have this charge. [In elementary particle physics, we now do talk of the *quarks* which are supposed to have charge, that are a fraction of the electron charge. Physicists talk of the *up quark* (charge $= +\frac{2}{3}$ e) and the *down quark* (charge $= -\frac{1}{3}$ e). The proton is supposed to be made up of two up and one down quark while the neutron is supposed to be made up of one up and two down quarks.]

Q.13. *What do you understand by the additive property of electric charge ?* (1)

Ans. The *additive* property of electric charge implies that the total net charge for any system, is the *algebraic* sum of all the charges present in it. This means that a combination of a charge –q and a charge + q results in a net charge equal to zero.

Q.14. *What is meant by 'electrostatic induction' ?* (2)

Ans. Suppose we have an uncharged electroscope and we bring a charged rod near its disc without touching it. We find that the leaves diverge. If we remove the rod without touching it with the disc the leaves collapse once again. It means that the mere presence of a charged rod near another object can cause it to get charged. We call this phenomenon of charging an object by bringing a charged body near it, but not touching, as electrical induction.

Q.15. *How can we understand the process of charging by induction ? Can we charge an insulator by induction ?* (2)

Ans. When a charged object (say positively charged) is brought near an uncharged conducting object (without touching it) it starts attracting the negatively charged electrons, present in the latter, towards itself. Thus, the *'near end'* of the uncharged object gets negatively charged while the *'far end'* gets positively charged. Now if the uncharged object is touched with the finger, its positively charged end loses its charge by attracting electrons from the earth through the human body. Now if the finger is removed *first* and then the charging object is also removed, the additional negative charge, drawn from the earth, gets distributed over the whole of the uncharged body which then gets negatively charged.

We *cannot* charge an insulator by induction because the charges in an insulator are not free to move.

Q.16. *Why do we say that 'induction always precedes attraction' ?* (2)

Ans. When the charged object is brought near the uncharged one, it induces a charge of the opposite kind on its 'near' end and a charge of the same kind on its 'far' end. The attractive force on the 'near' end is, thus, greater than the repulsive force on the 'far' end. The net force on the uncharged object is, thus, an attractive one. The uncharged object, therefore, gets pulled towards the charged one.

We can, therefore, assert that before getting attracted, the uncharged object first gets charged by induction. Hence, *induction precedes attraction.*

Q.17. *Give the salient features of 'charging by induction'.* (2)

Ans. During the process of charging by induction :

(i) The uncharged object acquires a charge opposite to that of the charging object.

(ii) The charging object's charge does not get reduced. It simply helps the uncharged object to share charges with the earth and, thus, gets charged. The earth, being so very large, a small addition to or removal of charge from it goes unnoticed in practice.

(iii) The same charged object may be repeatedly used to charge a number of objects by induction without any reduction whatsoever in its own charge.

Q.18. *Explain, with the help of suitable diagrams, the sequence of steps to be followed to charge an electroscope by induction.* (3)

Ans. The procedure for *charging an object by induction* is illustrated in steps (a), (b), (c), (d). As shown we have to follow the following steps, *strictly in this sequence,* to charge an object by induction:

(a) Bring a charged rod near the body.

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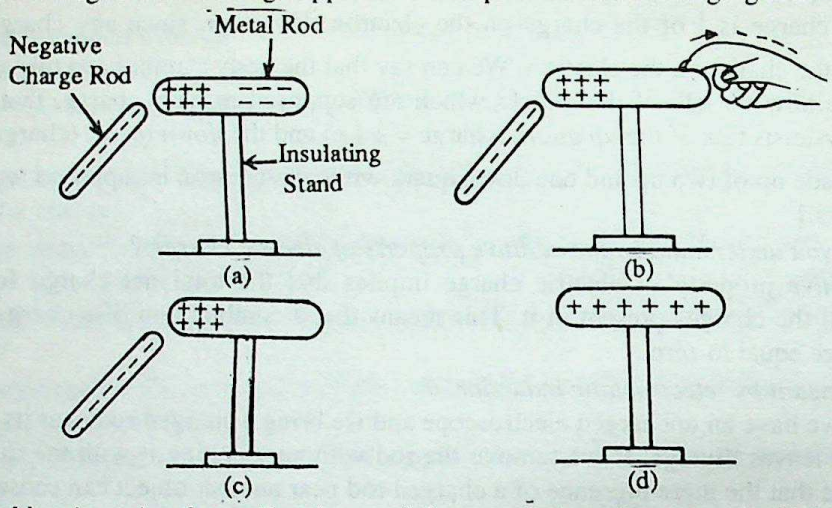
(b) Keeping the charged rod nearby, touch the body with fore finger.

(c) Remove the finger first, and then the charged rod.

(d) The body is now charged with a charge opposite to that present on the charging rod.



Q.19. *Ordinary rubber is an insulator. But the special tyres of aircrafts are made slightly conducting. Why is this necessary ?* **(2)**

Ans. Now-a-days the tyres of vehicles are often made by adding a carbon compound to the rubber. This is done to enable them to leak away any charge built up on the body of the vehicle, due to 'friction' against air, to the earth.

Q.20. *Why do vehicles carrying inflammable material and running on rubber tyres, always drag a chain along the ground ?* **(2)**

Ans. The metallic bodies of the vehicles often get charged because of the friction between them and the air rushing past them. This charge can produce a spark which can be extremely dangerous when the vehicles are carrying inflammable material, say petrol, etc. The rubber tyres do not (easily) let this charge leak into the earth. When, however, a chain dragging along the ground, is attached to the vehicle, the charge quickly leaks away to earth and the danger associated with it is thereby, avoided.

Q.21. *State Coulomb's law of force in electrostatics.* **(CBSE 1994) (1)**

Ans. According to Coulomb's law :

The electrostatic force of interaction between two charges q_1 and q_2, separated by a distance r, is

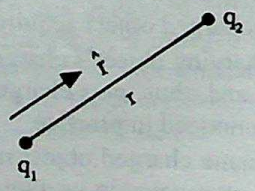
(i) directly proportional to the product $q_1\ 1_2$ of the two charges,

(ii) inversely proportional to the square of the distance betwehe them, and

(iii) acts along the line joining the two charges.

Defining $\hat{r}$ as the unit vector along the line joining q_1 and q_2, and directed from q_1 to q_2, we can say that the force $\mathbf{F}_{21}$, on charge q_2 (the test charge) due to the charge q_1 (the source charge) is given by

$$\mathbf{F}_{21} = k \frac{q_1 q_2}{r^2} \hat{r}$$



The constant of proportionality, k is written as $\left(\frac{1}{4\pi\epsilon_0}\right)$ in SI units, where it (nearly) has the value 9×10^9 N M^2 C^{-2}.

Q.22. *Write the complete explicit vector form of Coulomb's law.* **(1)**

Ans. We know that the force **F** due to a charge q_1 on another charge q_2 is given by

$$\mathbf{F} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} \hat{r}$$

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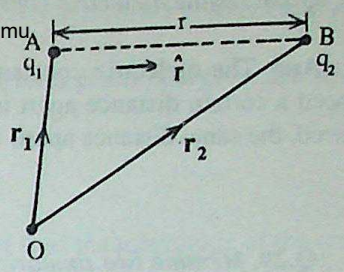
Here, r is the magnitude of the distance between q_1 and q_2 and $\hat{r}$ is a unit vector directed along the line drawn from q_1 to q_2.



Let us now suppose that the charges q_1 and q_2 are located at points A and B which are defined by position vectors $\mathbf{r}_1$ and $\mathbf{r}_2$ with respect to some fixed origin O. Calling the vector **AB** as r, we then have

$$\mathbf{r} = \mathbf{r}_2 - \mathbf{r}_1$$

The unit vector $\hat{r}$ from A to B, being the ratio of the vector AB and its magnitude, we have

$$\hat{r} = \frac{\mathbf{r}}{|\mathbf{r}|} = \frac{(\mathbf{r}_2 - \mathbf{r}_1)}{|\mathbf{r}_2 - \mathbf{r}_1|}$$

Now, $|\mathbf{r}_2 - \mathbf{r}_1|$ or $|\mathbf{r}|$ is nothing but r, the magnitude of the vector AB. Hence, $r = |\mathbf{r}_2 - \mathbf{r}_1|$

Substituting these values for r and $\hat{r}$ in the above expression for **F**, we have

$$\mathbf{F} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{|\mathbf{r}_2 - \mathbf{r}_1|^2} \cdot \frac{(\mathbf{r}_2 - \mathbf{r}_1)}{|\mathbf{r}_2 - \mathbf{r}_1|} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{|\mathbf{r}_2 - \mathbf{r}_1|^3} (\mathbf{r}_2 - \mathbf{r}_1)$$

This expression gives us the force on the charge q_2 due to the charge q_1. We state this fact more explicitly by replacing **F** by $\mathbf{F}_{21}$, the force on charge '2' due to charge '1'. Hence ,

$$\mathbf{F}_{21} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{|\mathbf{r}_2 - \mathbf{r}_1|^3} (\mathbf{r}_2 - \mathbf{r}_1)$$

This expression gives Coulomb's law in its explicit vector form.

Q.23. *On the basis of the explicit vector form of Coulomb's law, show that like charges repel and unlike charges attract each other.* **(2)**

Ans. Let q_1 and q_2 be *like* charges. The product $(q_1 q_2)$ is then necessarily positive. Hence, the direction of $\mathbf{F}_{21}$, the force on q_2 due to q_1 is that of $(\mathbf{r}_2 - \mathbf{r}_1)$ which, as we see, is such that q_2 must experience a force directed away from q_1. Hence, *like charges repel each other.*

When q_1 and q_2 are *unlike* charges, the product $(q_1 q_2)$ would be necessarily negative. The direction of $\mathbf{F}_{21}$ would then be opposite to that of $(\mathbf{r}_2 - \mathbf{r}_1)$. This means that q_2 experiences a force directed towards q_1. Hence, unlike charges attract each other.

Q.24. *Define the SI unit of electric charge.* **(CBSE 1994) (1)**

Ans. The SI unit of electric charge is the coulomb. An object is said to have a charge of one coulomb if it repels an exactly similarly charged object with a force of 8.98755×10^9 newton ($\cong 9 \times 10^9$ newton) when the two are kept apart a distance of one metre in vacuum.

Q.25. *What is the value of the constant of proportionality used in Coulomb's law in SI units?* **(1)**

Ans. The constant of proportionality, in SI units, in Coulomb's law, is $\frac{1}{4\pi\epsilon_0}$ and it has a value of 8.98755×10^9 N m^2 C^{-2}.

Q.26. *What is the value of permittivity of free space in SI units ?* **(1)**

Ans. The permittivity of free space is ϵ_0 and its value in SI units is 8.85×10^{-12} N^{-1} m^{-2} C^2.

Q.27. *Two charges q_1 and q_2, placed at a distance r apart in vacuum exert a force, say* **F** *on each other. If the same charges were similarly placed in a material medium, how will their mutual force of interaction get affected ?* **(1)**

Ans. The mutual force of interaction will get *reduced* by a factor ϵ_r, characteristic of the medium. We call ϵ_r as the *relative permittivity* (*or* dielectric constant) of the medium. Thus,

$\frac{F_{vacuum}}{F_{medium}} = \epsilon_r$, where ϵ_r is the relative permittivity of the medium.

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Q.28. *Define dielectric constant of a medium in terms of force between electric charges.*

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(CBSE 1997) (1)

Ans. The dielectric constant of a medium may be defined as the ratio of the force between two charges placed a certain distance apart in vacuum, to the force between the same two charges, when they are similarly placed, the same distance apart, in the given medium.

$$\text{Thus,} \quad K = \frac{F_{vacuum}}{F_{medium}}$$

Q.29. *Mention two similarities and two dissimilarities between electrostatic and gravitational interactions.* **(2)**

Ans. The following may be cited as two similarities between electrostatic and gravitational interactions :

(i) In both cases, the force of interaction is *directly proportional to the product* of the two entities (*masses* for gravitational and *charges* for electrostatic) responsible for the interaction.

(ii) In both cases, the force of interaction is *inversely proportional to the square of the distance* between the two interacting particles. Thus, both electrostatic and gravitational forces are *'inverse square law'* forces .

We may cite the following as the two dissimilarities between gravitational and electrostatic interactions.

(i) The gravitational forces between two masses is *always* an *attractive force*. The electrostatic force, however, *can be both attractive as well as repulsive* depending on whether the two charges are *unlike* or *like* charges.

(ii) The electrostatic force is very very strong in comparison to the gravitational force between a pair of 'charged masses'. Thus, for two protons, we find that $F_E/F_G \cong 10^{36}$.

Q.30. *Estimate the ratio of the electrostatic force of repulsion between two protons to the gravitational force of attraction between them.*

Given : mass of proton $\cong 1.67 \times 10^{-27}$kg, $G = 6.7 \times 10^{-11}$ SI-units,

charge of proton $\cong + 1.6 \times 10^{-19}$ C and $\frac{1}{4\pi\epsilon_0} \cong 9 \times 10^9$ SI units. **(2)**

Ans. We have

$$F_E = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2} \cong \frac{9 \times 10^9 \times (1.6 \times 10^{-19})^2}{r^2}$$

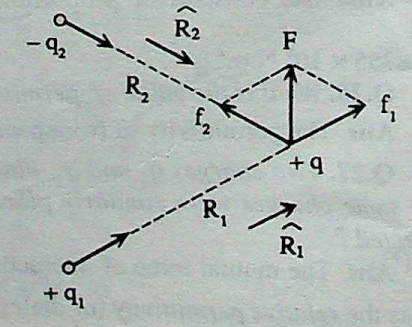
and

$$F_G = G\frac{m_1 m_2}{r^2} \cong \frac{6.7 \times 10^{-11} \times (1.67 \times 10^{-27})^2}{r^2}$$

$$\therefore \quad \frac{F_E}{F_G} = \frac{9 \times 10^9 \times (1.6)^2 \times 10^{-38}}{6.7 \times 10^{-11} \times (1.67)^2 \times 10^{-54}} \approx 10^{36}.$$

Q.31. *State the principle of superposition in electrostatics.* **(1)**

Ans. According to the principle of superposition, if a charge q is acted upon simultaneously by the electric forces from charges $q_1, q_2, q_3, \ldots\ldots q_n$, etc., the total force on q is the vector sum of the forces that q would experience if the individual charges were to act on q one at a time. This is illustrated by the following figure.



Illustrating the principle of superposition.

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Q.32. *Write down the complete explicit vector expression for the force which a discrete collection of n point charges ($q_1, q_2, ...q_n$) exerts on a test charge say, q.* **(1)**

Ans. In general, when there are n charges ($q_1, q_2, ...q_n$) exerting forces on a given charge q, the resultant force on q as per the principle of superposition, is given by

$$\mathbf{F} = \frac{1}{4\pi\epsilon_0} \sum_{j=1}^{N} \frac{q_j q}{R_j^2} \mathbf{R}_j ,$$

where $\hat{R}_j$ is a unit vector directed along the line joining q_j to q and R_j is the magnitude of the distance between q_j and q.

Q.33. *Force between two point charges kept at a distanced apart in air is F. If these charges are kept at the same distance in water, how does the force between them change?* **(CBSE 1997) (1)**

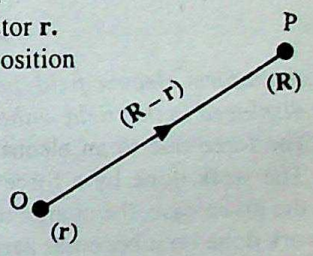
Ans. In water, the force between the charges kept at the same distance will become $\frac{F}{K}$, where K is the dielectric constant of water.

Q.34. *Does an electric charge experience a force due to the field that the charge itself produces?* **(1)**

Ans. No. We say that an electric charge experiences a force only due to the electric field produced by *'other'* charges.

Q.35. *Define the electric field at a point. Give its units and dimensions.* **(2)**

Ans. Let a charge q be located at a point O, defined by the position vector **r**. The *electric field* (**E**) due to this charge at a (field) point P, defined by the position vector R, is then defined by the equation.



$$\mathbf{E} = \frac{1}{4\pi\epsilon_0} \frac{q}{|\mathbf{R}-\mathbf{r}|^2} \frac{(\mathbf{R}-\mathbf{r})}{|\mathbf{R}-\mathbf{r}|}$$

or

$$\mathbf{E} = \frac{1}{4\pi\epsilon_0} \frac{q}{|\mathbf{R}-\mathbf{r}|^3} (\mathbf{R}-\mathbf{r})$$

Combining this definition with Coulomb's law, we notice that we can think of the electric field, at a given point, as the force experienced by a unit (test) charge kept at that point. We may say $\mathbf{E} = \underset{\Delta q \to 0}{\text{Lt}} \left(\frac{\Delta \mathbf{F}}{\Delta q}\right)$, where $\Delta\mathbf{F}$ is the force experienced by a charge Δq kept at the field point under consideration.

The units of the electric field are *newton per coulomb* (NC^{-1}), or equivalently, *volt per metre* (Vm^{-1}).

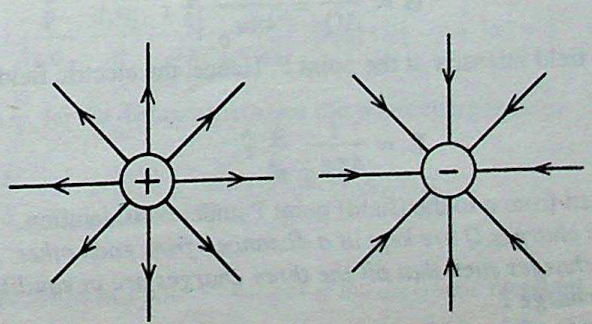
The dimensions of $|E|$ are $MLT^{-3}A^{-1}$.

Q.36. *Is electric field intensity a scalar or a vector quantity? What is its SI unit ?* **(1)**

Ans. Electric field intensity is a vector quantity. Its SI unit is NC^{-1} or Vm^{-1}.

Q.37. *Sketch the electric lines of force due to point charges (i) $q > 0$ and (ii) $q < 0$.* **(CBSE 1995) (2)**

Ans. The required sketches are as shown in the following figures:



(i) $q > 0$ (ii) $q < 0$

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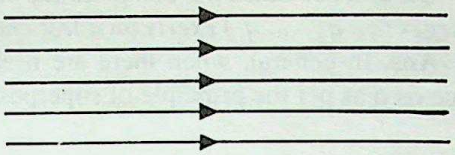
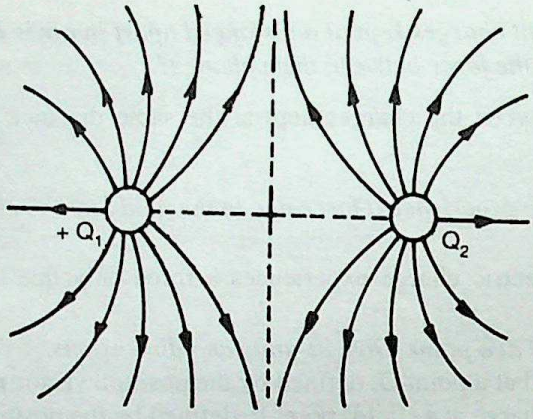
Q.38. *Draw lines of force to represent a uniform electric field.* **(1)**

Ans. The lines of force of a uniform electric field are equidistant parallel lines like the sketch shown alongside.



Q.39. *Sketch the electric lines of force for the positive charges Q_1 and Q_2 ($Q_1 > Q_2$) separated by a distance d.* **(CBSE 1997 Comptt.) (1)**

Ans.



Q.40. *A uniform electric field, parallel to the x-axis, is present in a certain region. In what direction can a charge be displaced in this field without any external work being done on it ?* **(1)**

Ans. The force due to an electric field, on a charged particle, is either parallel or antiparallel to the field direction. The work done by a force is zero only if the displacement is along a direction normal to the force. Hence, in the given case, the charge must be displaced either *along the y-axis* or *along* the *z-axis* in order that the external work done on it becomes zero.

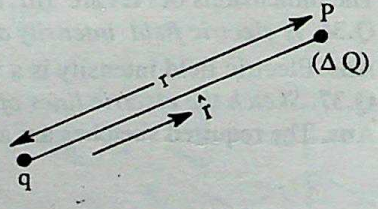
Q.41. *Derive the expression for the electric field, due to a point charge at a distance r from it.*

(CBSE 1994) (3)

Ans. The electric field intensity at a point is viewed as the force experienced by a unit positive charge kept at that point. Now, as per Coulomb's law, the force on a (small) charge of (ΔQ) coulomb, at a distance r from a point charge q, is given by

$$\mathbf{F} = \frac{1}{4\pi\epsilon_0}\,\frac{q \times (\Delta Q)}{r^2}\,\hat{\mathbf{r}}$$

Here, $\hat{\mathbf{r}}$ is a unit vector along the line joining the charge q to the point P where the charge of ΔQ is supposed to be kept.



Hence, the force per unit charge at point P (due to the point charge q) is

$$\mathbf{E} = \frac{\mathbf{F}}{\Delta Q} = \frac{1}{4\pi\epsilon_0}\,\frac{q}{r^2}\,\hat{\mathbf{r}}$$

This gives us the electric field intensity at the point P. Hence, the electric field intensity, at a distance r from a point charge q, is given by

$$\mathbf{E} = \frac{1}{4\pi\epsilon_0}\,\frac{q}{r^2}\,\hat{\mathbf{r}},$$

where $\hat{\mathbf{r}}$ is a unit vector directed from q to the (field) point P under consideration.

Q.42. *Two identical point charges Q are kept at a distance r from each other. A third point charge is placed on the line joining these two charges such that all the three charges are in equilibrium. What is the magnitude, sign and position of the third charge ?* **(CBSE 1994) (2)**

Ans. Let q be the magnitude of the third charge. It is obvious that it must be kept midway between the two charges (Q each) so that the force on it, due to these two charges, are equal and opposite to each other.

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Let us now calculate the force on the charge Q on the right due to the charge q and the charge Q on the left. The force on Q due to the other Q is

$$\mathbf{f}_1 = \frac{1}{4\pi\epsilon_0}\frac{Q^2}{r^2} \text{ towards right}$$

The force on the charge Q due to the charge q must, therefore, be towards left. Hence, q must have a sign opposite to that of Q. Further, the force $\mathbf{f}_2$ on Q due to q is

$$\mathbf{f}_2 = \frac{1}{4\pi\epsilon_0}\frac{Qq}{(r/2)^2} = \frac{4Qq}{4\pi\epsilon_0 r^2}.$$

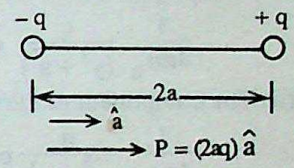
In order that the net force on Q be zero we must have

$$\frac{1}{4\pi\epsilon_0}\frac{4Qq}{r^2} = \frac{1}{4\pi\epsilon_0}\frac{Q^2}{r^2} \Rightarrow |q| = Q/4$$

Thus, the third charge q must have a magnitude Q/4, a sign opposite to that of Q and must be kept midway on the line joining the two charges Q and Q.

Q.43. *Define the term 'dipole moment'.* **(CBSE 1994) (1)**

Ans. Let -q and +q be the two (equal and opposite) point charges constituting a dipole. The direction of the line drawn from the (negative) charge –q to the (positive) charge +q is taken as the direction of the dipole axis. We may indicate this direction by the unit vector $\hat{a}$.



The vector. $\boldsymbol{l} = (2a)\,\hat{a}$ may be taken as the length vector for the given dipole.

The dipole moment **p** of a given dipole is defined as the product of magnitude of either of its constituent charges and its, length vector $\boldsymbol{l}$

$$\mathbf{p} = q.\boldsymbol{l}$$
$$= (2aq)\,\hat{\mathbf{a}}$$

The direction of the dipole moment vector **p** is, thus, from the negative to the positive charge.

Q.44. *In a medium the force of attraction between two point electric charges, distance d apart, is F. What distance apart should these be kept in the same medium so that the force between them becomes (i) 3F (ii) $\frac{F}{3}$?*

(CBSE 1998) (1)

Ans. We know that the force of attraction between two point changes q_1 and q_2 kept adistance apart is given by

$$F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{d^2} \qquad ...(i)$$

(i) For the force to become 3F, let the distance between the point charges be *x*.

$$\therefore\ 3F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{x^2} \Rightarrow 3\cdot\frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{d^2} = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{x^2} \text{ [from (i)]} \quad \Rightarrow 3x^2 = d^2 \ \Rightarrow\ x = \frac{d}{\sqrt{3}}$$

(ii) For the force to become $\frac{F}{3}$, let the distance between the point charges be y.

$$\therefore\ \frac{F}{3} = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{y^2} \quad \Rightarrow \frac{1}{3}\cdot\frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{d^2} = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{y^2} \text{ [from (i)]}$$

$$\Rightarrow y^2 = 3d^2 \Rightarrow y = \sqrt{3}\,d.$$

Q. 45. *How does the force between two points changes if the dielectric constant of the medium in which they are kept increases?* **(CBSE 1999) (1)**

Ans. The force between the two point charges decreases.

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Q.46. *Define electric dipole moment. Derive an expression for the electric field intensity at any point along the equatorial line of a dipole .* **(CBSE 1993, 1994) (3)**

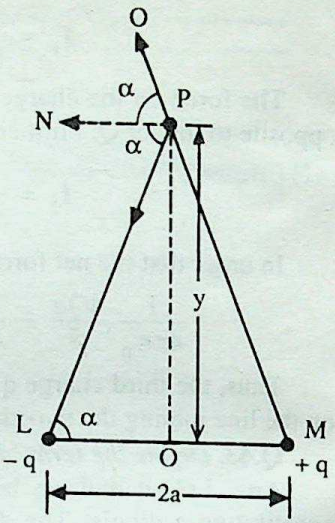
Ans. See answer to question 43 for 1st part.

Electric Field due to a Dipole at an Equatorial Point

The line, perpendicular to the dipole axis and passing through its mid-point O is known as the equatorial line of the given dipole. We may calculate the field at a point P on this line by taking the vector sum of the fields there due to each of the charges making up the dipole.

The distance of each charge from the field point is $(y^2 + a^2)^{1/2}$. Hence, the magnitude of the field at P due to either charge is

$$\frac{1}{4\pi\epsilon_0}\frac{q}{(y^2 + a^2)}$$



Now the fields, due to the charges –q and +q, are directed along the direction PL and MP respectively. The symmetry of the situation tells us that we can add the two vectors conveniently by resolving them into components along PN (the line antiparallel to LM, i.e., $\hat{a}$) and OP respectively. We have

(i) The components of the field at P due to the charge –q are

$$\frac{1}{4\pi\epsilon_0}\frac{q}{(y^2 + a^2)} \cos\alpha \text{ along PN}$$

(ii) The component of the field at P due to the charge +q are

$$\frac{1}{4\pi\epsilon_0}\frac{q}{(y^2 + a^2)} \cos\alpha \text{ along PN} \quad \text{and} \quad \frac{1}{4\pi\epsilon_0}\frac{q}{(y^2 + a^2)} \sin\alpha \text{ along OP.}$$

The sum total of the component is, thus,

$$2 \times \frac{1}{4\pi\epsilon_0}\frac{q}{(y^2 + a^2)} \cos\alpha \text{ along PN.}$$

(The other two components cancel each other). Hence,

$$\mathbf{E} = 2 \times \frac{1}{4\pi\epsilon_0}\frac{q}{(y^2 + a^2)} \cos\alpha\,(-\hat{a}) = 2 \times \frac{1}{4\pi\epsilon_0}\frac{q}{(y^2 + a^2)} \cdot \frac{a}{(y^2 + a^2)^{1/2}}(-\hat{a})$$

$$\left[\because \text{ from } \Delta \text{ LOP, } \cos\alpha = \frac{\text{LO}}{\text{LP}} = \frac{a}{(y^2 + a^2)^{1/2}}\right]$$

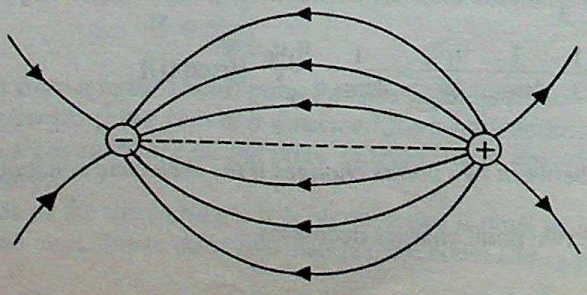
$$\therefore \quad \mathbf{E} = \frac{p}{(4\pi\epsilon_0)(y^2 + a^2)^{3/2}}(-\hat{a}) = \frac{1}{4\pi\epsilon_0}\frac{-\mathbf{p}}{(y^2 + a^2)^{3/2}}$$

The field, at a point on the equatorial line, is thus, seen to be directed antiparallel to the dipole axis or the dipole moment vector, i.e., vector **p**.

Q.47. *What is a dipole ? Give the units of dipole moment. Draw electric lines of force for an electric dipole.* **(CBSE 1993 Comptt.) (3)**

Ans. A dipole is a system of two equal and opposite point charges (+q and –q) separated by a finite distance 2a. The units of the dipole moment are coulomb-metre (C m).

The electric lines of force of a dipole are as shown below:



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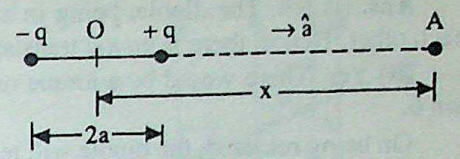
Q.48. *Derive the expression for the electric field (E) and (ii) potential due to an electric dipole.* **(CBSE 1995)(3)**

Ans. Let the dipole be made up of two equal and opposite charges –q and +q separated by a distance 2a. We are interested in the field at a point A distant x from the centre O of the dipole.



The dipole moment, **p**, of the dipole is given by $\mathbf{p} = (q \cdot 2a)\hat{a}$, where $\hat{a}$ is a unit vector along the line going –q to +q.

The electric field, **E**, at A is the sum of the electric fields there due to the two charges +q and –q of the dipole. We have field at A due to the charge (+q) $= \frac{1}{4\pi\epsilon_0}\frac{q}{(x-a)^2}\hat{a}$

and field at A due to the charge $(-q) = \frac{1}{4\pi\epsilon_0}\frac{-q}{(x+a)^2}\hat{a}$

Hence, $\mathbf{E} = \frac{q}{4\pi\epsilon_0}\left[\frac{1}{(x-a)^2} - \frac{1}{(x+a)^2}\right]\hat{a}$ $\left\{= \frac{q}{4\pi\epsilon_0}\cdot\frac{4xa}{(x^2-a^2)}\hat{a}\right.$

$= \frac{1}{4\pi\epsilon_0}\frac{2px}{(x^2-a^2)^2}\hat{a} = \frac{1}{4\pi\epsilon_0}\frac{2x}{(x^2-a^2)^2}\mathbf{p}$

This gives us the field of a dipole at an axial point.

When x is very large compared to a that we may neglect terms of the order of a^2/x^2 (and higher powers in a/x), we may write

$$\mathbf{E} = \frac{1}{4\pi\epsilon_0}\frac{1}{x^4}\frac{2px}{(1-a^2/x^2)^2}\hat{a} \approx \frac{1}{4\pi\epsilon_0}\frac{2p}{x^3}\hat{a} = \frac{1}{4\pi\epsilon_0}\frac{2\mathbf{p}}{x^3}$$

This gives us the (approximate) *far field* of a dipole at an axial point.

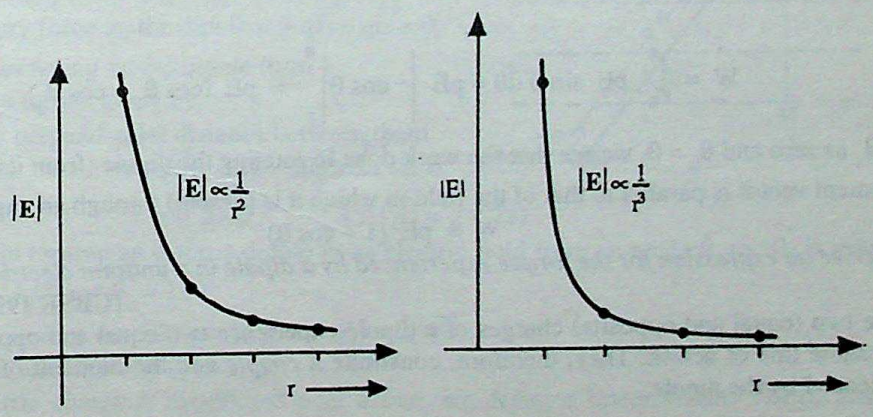
Q.49. *For equidistant axial and equatorial points, what is the ratio of the electric field due to a small dipole ?* **(1)**

Ans. For equidistant points, the axial field of a (very) small dipole is twice its equatorial field. Thus, for a (very) small dipole.

$$\frac{\text{Field at an axial point}}{\text{Field at an (equidistant) equatorial point}} = 2$$

Q.50. *Compare the manner in which |E| varies with r for a point charge and an electric dipole.* **(2)**

Ans. The magnitude of **E** varies as $1/r^2$ for a point charge and as $1/r^3$ for a dipole. This is diagrammatically shown in figs. (a) and (b) below:



(a) Point charge field (b) Dipole field

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Q.51. *An electric dipole is held at an angle θ in a uniform external electric field* **E**. *Will there be any (i) net translating force, (ii) torque acting on the dipole ? What happens to the dipole on being released ?*

(CBSE 1994) (2)

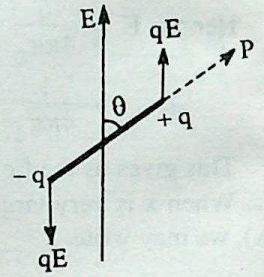
Ans. (i) No. The dipole, being in a uniform field, the forces on its two charges are equal and opposite to each other. Hence, there is *no net* translating *force* on the dipole.

(ii) Yes. There would be a torque on the dipole. This torque is given by $\mathbf{p} \times \mathbf{E}$ and as a magnitude pE sin θ.

On being released, the dipole will tend to align itself parallel to the field. This is because of the action of the torque ($\mathbf{p} \times \mathbf{E}$) acting on it. However, because of its inertia, it would overshoot the equilibrium position and continue to oscillate for a while before finally coming to rest with its dipole moment vector **p** parallel to the field.

Q.52. *Prove that the net force acting on an electric dipole, inclined at an angle θ to a uniform electric field E, is zero. Draw a suitable diagram.* **(CBSE 1993 Comptt.) (2)**

Ans. Let **E** be the uniform electric field in which a dipole made up of charges (−q) and (+q), separated by a distance 2a is present. The charge (+q) then experiences a force q**E** in the direction parallel to that of the field while the charge (−q) experiences a force q**E** in a direction antiparallel to that of the field. Since there are two equal and opposite forces, acting on the dipole, the net force on the dipole is zero.

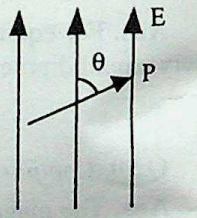


Q.53. *Define the term electric dipole moment. Derive an expression for the total work done in rotating the dipole through an angle θ in a uniform electric field.* **(CBSE 1993, 1995) (3)**

Ans. See answer to Q. No. 46 for definition of the 'dipole moment'.

We know that when a dipole of moment **p** is present in an electric field E, it experiences a torque τ ($= \mathbf{p} \times \mathbf{E}$) which tends to align it parallel to the field. This implies that when the dipole axis is making an angle θ with the field, the torque experienced by the dipole has magnitude τ, where

$$\tau = pE \sin\theta.$$



The work done by this torque in turning the dipole through a further angle dθ is then

$$dW = \tau d\theta = pE \sin\theta \, d\theta$$

∴ The work done in turning the dipole from an initial position ($\theta = \theta_1$) to a final position ($\theta = \theta_2$) is given by

$$W = \int_{\theta_1}^{\theta_2} pE \sin\theta \, d\theta = pE \left| -\cos\theta \right|_{\theta_1}^{\theta_2} = pE \, (\cos\theta_1 - \cos\theta_2)$$

Taking θ_1 as zero and $\theta_2 = \theta$, we see that the work done in rotating the dipole (from its initial position where its dipole moment vector is parallel to that of the field in which it is present) through an angle θ is

$$W = pE \, (1 - \cos\theta)$$

Q.54. *Derive an expression for the torque experienced by a dipole in a uniform electric field.*

(CBSE 1993 Comptt., 1998) (3)

Ans. The two (equal and opposite) charges of a dipole experience two equal and opposite forces which do not have the same line of action. They, therefore, constitute a *couple* and the moment of this couple gives the torque experienced by the dipole.

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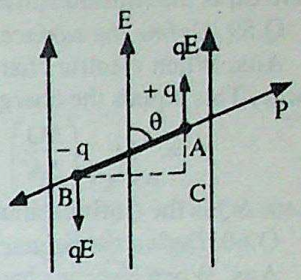
We now calculate the torque experienced by a dipole in a uniform electric field. Let the dipole moment vector **p** be at an angle θ to the direction of the uniform electric field **E**. Referring to the following fig. the torque is given by

$$\tau = F \times AC$$
$$= qE \times 2a \sin\theta$$
$$= pE \sin\theta,$$

where **p** = q.2a = dipole moment



Since this torque has tendency to align, the dipole parallel to the field, the above equation, in vector notation, can be expressed as $\tau = \mathbf{p} \times \mathbf{E}$.

Thus, a dipole, in uniform electrostatic field, experiences a torque $\tau = \mathbf{p} \times \mathbf{E}$, which tends to align it along the field. The net force on the dipole is, however, zero.

Q.55. *Two point electric charges of unknown magnitude and sign are placed a distance d apart. The electric field intensity is zero at a point not between the charges but on the line joining them. Write two essential conditions for this to happen.* **(CBSE 1997) (2)**

Ans. The two essential conditions are:

(i) The two charges must be of opposite sign.

(ii) The two charges must have different magnitudes.

Q.56. *Define intensity of electric field at a point. At what points is the electric dipole field intensity parallel to line joining the charges?* **(CBSE 1997) (2)**

Ans. Electric field intensity at a point is defined as the force experienced by a unit positive charge placed at that point.

The electric dipole field intensity at all the points on the equatorial line of the dipole is parallel to the line joining the charges.

Q.57. *An electric dipole is held in a uniform electric field.*

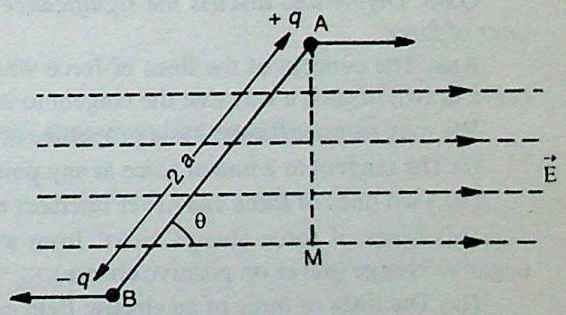
(i) Show that no translatory force acts on it.

(ii) Derive an expression for the torque acting on it.

(iii) The dipole is aligned parallel to the field. Calculate the work done in rotating it through 180°.

(CBSE 1997 Comptt., 1999) (5)

Ans. In the following figure, AB is an electric dipole of length 2a, consisting of charges +q and –q and placed in a uniform electric field $\vec{E}$ making an angle θ with it.



(i) Force on charge +q at A = $+q\vec{E}$

Force on charge –q at B = $-q\vec{E}$

∴ Total translatory force on the dipole = $+q\vec{E} - q\vec{E} = 0$.

(ii) The two forces acting on the dipole form a couple, which exerts a torque given by

τ = either force × perpendicular distance between them

$$= q\vec{E} \times AM = q\vec{E} \times 2a \sin\theta$$

$$= p\vec{E} \sin\theta \qquad (\because |\vec{p}| = q \times 2a)$$

(iii) Work done in turning an electric dipole in an electric field from an angle θ_1 to θ_2 is given by $W = p\vec{E}(\cos\theta_1 - \theta_2)$, here $\theta_1 = 0°$ and $\theta_2 = 180°$

∴ $W = p\vec{E}(\cos 0° - \cos 180°) = \vec{E}[1 - (-1)] = 2p\vec{E}$

Q.58. *Define the linear density of charge.* **(1)**

Ans. When electric charge is distributed over a line, we define a linear density (λ) of this charge. This equals the charge per unit length of the line, i.e.

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$$\lambda = \underset{\Delta l \to 0}{\text{Lt}} \left(\frac{\Delta q}{\Delta l} \right) = \frac{dq}{dl},$$

where Δq is the (infinitesimal) charge over an (infinitesimal) length Δl of the line charge.

Q.59. *Define the surface density of charge.*

Ans. When electric charge is distributed over a plane (or a surface), we define a surface density (σ) of this charge, This equals the charge per unit area of the surface, i.e.

$$\sigma = \underset{\Delta A \to 0}{\text{Lt}} \left(\frac{\Delta Q}{\Delta A} \right) = \frac{dQ}{dA},$$

where ΔQ is the (infinitesimal) charge over an (infinitesimal) area ΔA.

Q.60. *Define the volume density of charge.* **(1)**

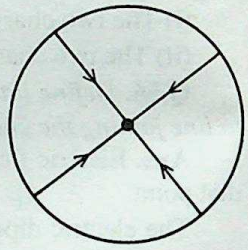
Ans. When electric charge is distributed in space (or over a volume), we define a volume density (ρ) of this charge. This equals the charge per unit volume of the space, i.e.

$$\rho = \underset{\Delta \tau \to 0}{\text{Lt}} \left(\frac{\Delta Q}{\Delta \tau} \right) = \frac{dQ}{d\tau},$$

where ΔQ is the (infinitesimal) charge present over an (infinitesimal) volume $d\tau$.

Q.61. *What is the intensity of the electric field at the centre of a uniformly charged ring ?* **(1)**

Ans. The intensity or the electric field intensity, at the centre of a uniformly charged ring, is zero. [This is because the (equal and opposite) fields of all the pairs of diametrically, opposite charge elements (into which the whole ring can be divided) cancel each other mutually]



Q.62. *Why does a man sitting inside an insulated metallic cage, not receive any shock even when the cage is gradually given a high charge ?* **(2)**

Ans. The electric field inside a charged conductor is known to be zero. (This is because of the inverse square law's nature of the electric field). Hence, when a man is sitting inside an insulated metallic cage, he does not receive any shock (even when the cage is gradually given a high charge) because the electric field intensity at his location is (always) zero.

Q.63. *Define and discuss the significance of the concept of lines of force. List important properties of the lines of force.* **(3)**

Ans. The concept of the lines of force was introduced by Michael Faraday. A line of force is an imaginary curve drawn in such a way that the tangent to it at any point gives the direction of the field at that point.

We may summarize the basic properties of the lines of force of an electric field as follows :

(*i*) The tangent to a line of force at any point gives the *direction* of the electric field vector at that point.

(*ii*) Two lines of force can never intersect each other.

(*iii*) Lines of force always 'start' from a positive charge (*never* from a negative charge) and 'end' on a negative charge (*never* on positive charge).

(*iv*) The lines of force of an electric field can never form closed loops.

(*v*) The number of lines of force per unit area normal to the field at any point gives the field strength at that point.

(*vi*) The lines of force are closely packed in regions of strong field and are wide apart in regions of weak field.

Q.64. *Why don't two electric lines of force ever intersect ?* **(2)**

Ans. Two electric lines of force can never intersect because, if they were to do so, the field at the point of intersection, could be along any of the (two different) tangents to the (two different) lines of force. This is physically not permissible.

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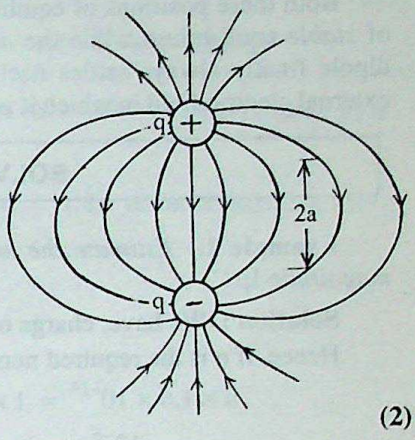
Q.65. *Can the lines of force of an electric field form closed loops ?* **(1)**

Ans. No. The lines of force of an electric field can never form closed loops because they must start from a positive charge and end on a negative charge. (The positive and the negative charges are respectively, the *source* and the *sink* for the lines of force of an electric field).

Q.66. *A test charge is placed at a point in a non uniform electric field. Will it necessarily move along the line of force passing through that point ?* **(2)**

Ans. The lines of force of a given electrostatic field are curves such that the tangent to the curve at any point give the direction of the field at that point. Now, the force on a charge q being given by $\mathbf{F} = q\mathbf{E}$, it follows that $\mathbf{F}$ is along (or antiparallel) to $\mathbf{E}$. Further, the direction of the force is 'in general' that of the acceleration and not that of velocity. It follows that a charged particle, when released in an electric field, will, in general, not move along the lines of force.



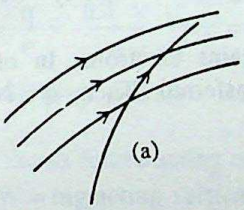
Q67. *What is the total number of lines of force emanating from a charge of one coulomb?* **(1)**

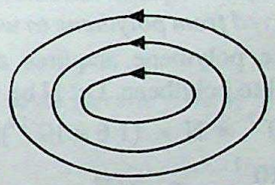
Ans. The total number of lines of force, starting from a charge of one coulomb, is $\left|\frac{1}{4\pi\epsilon_0}\right|$. i.e., 9×10^9 (nearly).

Q.68. *Draw the sketch of the lines of force of an electric dipole.* **(2)**

Ans. The sketch of the lines of force of an electric dipole is shown alongside.

Q.69. *Can any of the two sketches shown alongside, represent the lines of force of an electric field?* **(2)**





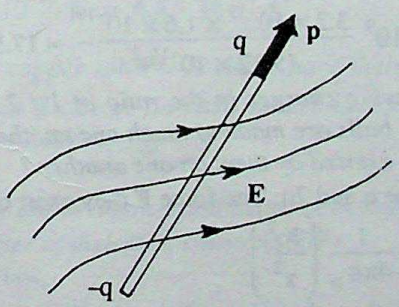
Ans. No. This is because

(i) in (a), two lines of force are crossing each other

(ii) in (b), the lines of force are shown as forming a closed loop.

Q70. *Is the following statement correct ?*

'An electric dipole, placed in an inhomogeneous electric field, will experience only a torque'. **(2)**



Ans. No. In an inhomogeneous electric field, an electric dipole will experience both a net translatory force as well as a torque.

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Q.71. *An electric dipole is in equilibrium in a uniform external electric field. What are the two possib values of the angle between its dipole moment vector and the electric field ?*
Are the two equilibrium positions of the dipole equivalent ? If not, how ?

Ans. The dipole can be in equilibrium both when its dipole moment vector (**p**) is parallel ($\theta = 0$) antiparallel ($\theta = \pi$) to the direction of the uniform external field (**E**) in which it is present. (This is because, both these cases, the magnitude of the torque (= pE sin θ), acting on the dipole is zero. The net force, on th dipole is, of course, zero for all its positions in a uniform electric field).

Both these positions of equilibrium are, however, not equivelent. The parallel position ($\theta = 0°$) is a positio of *stable* equilibrium while the *antiparallel* position ($\theta = \pi$) is a position of *unstable* equilibrium. Hence, th dipole finally always settles itself in the position where its dipole moment vector is parallel to the unifor external electric field in which it is present.

SOLVED NUMERICAL PROBLEMS ON UNIT – IA

Example 1. *Estimate the number of electrons that a body must lose, or gain, to acquire a charge o magnitude* $1\mu C$.

Solution : We have, charge on electron = 1.6×10^{-19} C
Hence, if n is the required number of electrons, we have

$$n \times 1.6 \times 10^{-19} = 1 \times 10^{-6}$$

$$\therefore \quad n = \frac{10^{-6}}{1.6 \times 10^{-19}} = \mathbf{6.25 \times 10^{12}} \textbf{ electrons}$$

Example 2. *A polythene piece rubbed with wool acquires a negative charge of* 4.8×10^{-7} *C. How many electrons are transferred from polythene to wool or vice-versa ?*

Solution : Since polythene acquires a negative charge it gains electrons. In other words, electron transferred from wool to polythene. Let N be number of electrons transferred . Then, $q = Ne$

or $\quad 4.8 \times 10^{-7} = N \times (1.6 \times 10^{-19})$

$$\therefore \ N = \frac{4.8 \times 10^{-7}}{1.6 \times 10^{-19}} = \mathbf{3 \times 10^{12}}$$

Example 3. *Calculate the force between an alpha particle and a proton separated by* 5.12×10^{-15} *m.*
(C.B.S.E. 1992)

Solution : q_1 = Charge on alpha particle = $2 \times 1.6 \times 10^{-19}$ C
q_2 = Charge on proton = 1.6×10^{-19} C
r = distance between alpha particle and proton = 5.12×10^{-15} m

From Coulomb's law , $F = 9 \times 10^9 \ \dfrac{3.2 \times 10^{-19} \times 1.6 \times 10^{-19}}{(5.12 \times 10^{-15})^2} = \mathbf{17.58\ N}$

Example 4. *Two small balls having charges in the ratio of 1 : 2 exert a force F on one another when placed at a distance x apart. The two balls are made to touch one another and separated. If they are now placed same distance apart what is the force exerted by them on one another ?*

Solution : Let the two charges be q and 2q. The force **F** they exert on one another is

$$\mathbf{F} = \frac{1}{4\pi\epsilon_0} \frac{q \times (2q)}{x^2} = \frac{1}{4\pi\epsilon_0} \left(\frac{2q^2}{x^2} \right)$$

When the two balls touch one another, they share their charge. Charge on each ball after touching is (q + 2q) / 2 = 1.5 q. The force $\mathbf{F}_1$ they exert on one another is

$$\mathbf{F}_1 = \frac{1}{4\pi\epsilon_0} \frac{(1.5q) \times (1.5\,q)}{x^2} = \frac{1}{4\pi\epsilon_0} \frac{2.25\,q^2}{x^2} = \mathbf{1.125\ F\ N}$$

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Example 5. *How far apart should two electrons be so that their electrostatic repulsion, on each other, equals the weight of the electron ? Take g = 10 ms^{-2}.*

Solution : Let x be the required distance. We then have

$$\frac{1}{4\pi\epsilon_0}\frac{(e)(e)}{x^2} = mg \Rightarrow x = \left(\frac{1}{4\pi\epsilon_0}\frac{e^2}{mg}\right)^{1/2}$$

$$= \left(\frac{9\times10^9}{9.1\times10^{-31}\times10}\right)^{1/2} \times (1.6\times10^{-19})\ m \cong \sqrt{10}\times10^{19}\times1.6\times10^{-19}\ m \approx \mathbf{5.05\ m}$$

Example 6. *Two identical positive ions exert a force of 14.75 × 10^{-7} N on each other when separated by a distance of 5Å. How many electrons are missing from each ion ?*

Solution : Let q be charge on each ion. Then, $F = 9\times10^9 \times \frac{q^2}{r^2}$, where r is the distance between ions.

Given $F = 14.75\times10^{-7}$ N; $r = 5Å = 5\times10^{-10}$ m

$$\therefore\ 14.75\times10^{-7} = \frac{9\times10^9\times q^2}{(5\times10^{-10})^2}$$

or $$q^2 = \frac{14.75\times10^{-7}\times25\times10^{-20}}{9\times10^9} = 40.97$$

$$\therefore\ q = \sqrt{40.96}\times10^{-18}\ C = \mathbf{6.4\times10^{-18}\ C}$$

Let n be number of elecrons missing from each ion. Then q = ne

or $$n = \frac{q}{e} = \frac{6.4\times10^{-18}}{1.6\times10^{-19}} = \mathbf{40}$$

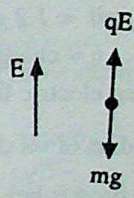
Example 7. *If an oil drop of weight 3.2 × 10^{-13} N is balanced in an electric field of 5 × 10^5 Vm^{-1}, find the charge on oil drop.* **(C.B.S.E 1993)**

Solution : Figure shows forces acting on oil drop.

(i) Weight, W = mg acting vertically downwards,

and (ii) The force, F = qE due to the electric field.

Since the drop is balanced, the two forces are equal in magnitude, i.e.,



$$qE = W \text{ or } q = \frac{W}{E}$$

Given $W = 3.2\times10^{-13}$ N, $E = 5\times10^5$ Vm^{-1}

$$\therefore\ q = \frac{3.2\times10^{-13}}{5\times10^5} = 0.64\times10^{-18}\ C = \mathbf{6.4\times10^{-19}\ C}$$

Example 8. *Two insulated charged copper spheres A and B have their centres separated by a distance of 50 cm. What is mutual force of replusion if charge on each sphere is 6.5 × 10^{-7} C. The radii of A and B are negligible compared to the distance of separation.*

What is force of replusion if

(i) each sphere is charged double the above amount and distance between them is halved?

(ii) the two spheres are placed in water of dielectric constant 80? **(C.B.S.E. 1990)**

Solution : According to Coulomb's law,

$$F = 9\times10^9\ \frac{q_1 q_2}{r^2}$$

Given $q_1 = q_2 = 6.5\times10^{-7}$ C; r = 50 cm = 0.5 m

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$$\therefore \quad F = \frac{9\times10^9\times(6.5\times10^{-7})^2}{(0.5)^2}\ N = 1521\times10^{-5}\ N = \mathbf{1.521\times10^{-2}\ N}.$$

(i) Let F′ be force between spheres when charge on each is doubled and their distance apart is halved. Now

$$q_1' = q_2' = 2\times6.5\times10^{-7}\ C;\ r' = r/2 = 0.25\ m$$

$$\therefore \quad F' = \frac{9\times10^9\,(13\times10^{-7})^2}{(0.25)^2}\ N = 24336\times10^{-5} = \mathbf{0.24336\ N}.$$

(ii) Let F″ be force between the two spheres when placed in water. Then F″ = F/K, where K is dielectric constant of water.

$$\therefore \quad F'' = \frac{1.521\times10^{-2}}{80}\ N = \mathbf{1.9\times10^{-4}\ N}.$$

Example 9. *An electron moves a distance of 6.0 cm when accelerated from rest in an electric field of strength $2\times10^4\ NC^{-1}$. Calculate the time of travel.*

Solution : The force F, acting on the electron due to the applied electric field E is F = eE, where e is charge on electron. Given $E = 2\times10^4\ NC^{-1}$. Therefore ,

$$F = eE = 1.6\times10^{-19}\times2\times10^4\ N = 3.2\times10^{-15}\ N$$

The acceleration of electron is $a = \frac{F}{m_e} = \frac{3.2\times10^{-15}}{9.1\times10^{-31}}\ ms^{-2} = 3.516\times10^{15}\ ms^{-2}$

Now, $u = 0$; $a = 3.516\times10^{15}\ ms^{-2}$, $s = 6\times10^{-2}$ m ; t = ?

Therefore, $s = ut + (1/2)\ a\,t^2$

or $6\times10^{-2} = (1/2)\times3.516\times10^{15}\times t^2$

or $t = \sqrt{\left(\frac{12\times10^{-2}}{3.516\times10^{15}}\right)} = \mathbf{5.8\times10^{-9}\ s}.$

Example 10. *An oil drop having excess of 10 electrons is held stationary under a uniform electric field of $3.142\ Vcm^{-1}$ in Millikan's oil drop experiment. What is radius of oil drop ?*

Density of oil = 1.2 g/c.c, $g = 10\ ms^{-2}$ Charge on electron = 1.6×10^{-19} C

Solution : q = charge on oil drop = $10\times1.6\times10^{-19}\ C = 1.6\times10^{-18}\ C$

E = applied electric field = $3.142\ Vcm^{-1} = 3.142\times10^2\ Vm^{-1}$

Let r be radius of oil drop. The mass, m of oil drop is, $m = \frac{4\pi}{3}r^3\rho$

Since the drop is held stationary; the force due to applied electric field is equal and opposite to weight of oil drop, i.e., qE = mg

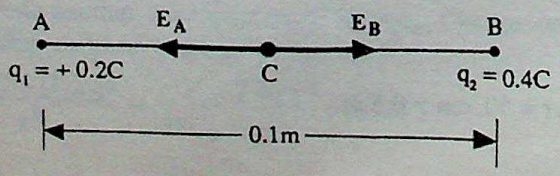
$$1.6\times10^{-18}\times3.142\times10^2 = \frac{4\times3.142}{3}r^3\times1.2\times10^3\times10$$

$$\therefore\ r^3 = \frac{1.6\times3.142\times3\times10^{-16}}{4\times3.142\times1.2\times10^4} = 10^{-20}$$

$$\therefore\ r = \sqrt[3]{10}\times10^{-7}\ m = 2.15\times10^{-7}\ m = \mathbf{2.15\times10^{-4}\ mm}.$$

Example 11. *Two point charges $q_1 = +0.2C$ and $q_2 = +0.4C$ are placed 0.1 m apart. Calculate the electric field at (a) the mid-point between the charges and (b) at a point on the line joining q_1 and q_2 such that it is 0.05 m away from q_2 and 0.15 m away from q_1.* **(C.B.S.E. 1993)**

Solution :



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In fig. C is point mid-way between charges q_1 and q_2 placed at A and B.

$|\mathbf{E}_A|$ = magnitude of electric field at C due to charge at A

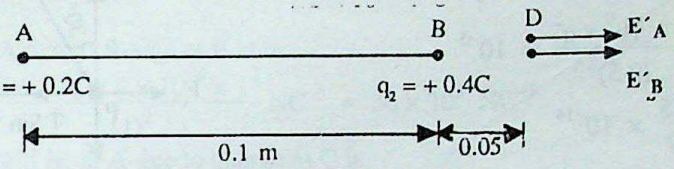
$$= \frac{9\times10^9\times0.2\times1}{(0.05)^2} = 0.072\times10^{13} = 7.2\times10^{11}\ \text{NC}^{-1}$$

$|\mathbf{E}_B|$ = magnitude of electric field at C due to charge at B

$$= \frac{9\times10^9\times0.4\times1}{(0.05)^2} = 14.4\times10^{11}\ \text{NC}^{-1}$$

Since, $\mathbf{E}_B$ is more than $\mathbf{E}_A$, the resultant field **E** is in direction $\mathbf{E}_B$. The magnitude of resultant field E is

$$E = E_B - E_A = 14.4\times10^{11} - 7.2\times10^{11} = \mathbf{7.2\times10^{11}\ NC^{-1}}$$



(b) In fig. D is point where electric field is to be calculated obviously

$|\mathbf{E'}_A|$ = magnitude of electric field at D due to charge at A

$$= \frac{9\times10^9\times0.2\times1}{(0.15)^2} = 0.8\times10^{11}\ \text{NC}^{-1}$$

$|\mathbf{E'}_B|$ = magnitude of electric field at D due to charge at B

$$= \frac{9\times10^9\times0.4\times1}{(0.05)^2} = 14.4\times10^{11}\ \text{NC}^{-1}$$

Since, both $\mathbf{E'}_A$ and $\mathbf{E'}_B$ are in same direction the magnitude of resultant field E′ at point D is

$$E' = E'_A + E'_B = 0.8\times10^{11} + 14.4\times10^{11} = \mathbf{15.2\times10^{11}\ NC^{-1}}$$

Example 12. *Two point electric charges of values q and 2q are kept at a distance a apart from each other in air. A third charge Q is to be kept along the same line in such a way that the net force acting on q and 2q is zero. Calculate the position of change Q in terms of q and d.* **(CBSE 1998)**

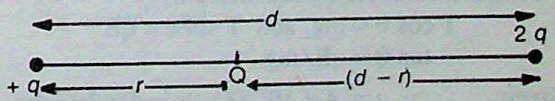
Solution: Consider the following figure wherein Q is placed at a distance r from charge q

Force of interaction between q and 2q in absence of Q is $\frac{1}{4\pi\epsilon_0}\frac{q\cdot2q}{d^2} = \frac{1}{4\pi\epsilon_0}\frac{1q^2}{d^2}$

For the net force on q and 2q to be zero, we must have

$$\frac{1}{4\pi\epsilon_0}\cdot\frac{q\cdot Q}{r^2} = \frac{1}{4\pi\epsilon_0}\frac{Q\cdot2q}{(d-r)^2}$$

$$\Rightarrow \frac{1}{r^2} = \frac{2}{(d-r)^2} \quad \Rightarrow \frac{1}{r} = \frac{\sqrt{2}}{d-r} \quad \Rightarrow \sqrt{2}\,r = d - r$$



$$\Rightarrow r = \frac{d}{\sqrt{2}+1} = d(\sqrt{2}-1)$$

Hence, the charge Q must be placed at a distance of $d(\sqrt{2}-1)$ from the charge q.

Example 13. *Two small sized identical balls each of mass 0.1732 q, carry identical charges . The balls are suspended from same point by strings of equal length. In equilibrium the angle between the strings is 60°. If length of each string is 0.5 m, what is the charge on either ball ?*

Solution : Fig. below shows the two balls P and Q, suspended from a common point O, in equilibrium. The forces acting are :

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(i) The weight W = mg of ball acting vertically downwards.

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(ii) The electrostatic force of replusion, $\mathbf{F}_{el}$ between the two balls, from Coulomb's law $\mathbf{F}_{el} = 9 \times 10^9 \frac{q^2}{r^2}$, where r = distance between balls in equilbrium. Since OPQ is an equilateral triangle r = OP = OQ = 0.5 m

(iii) The tension T, in the string.

In equilibrium

$T \cos 30^\circ = mg$ and $T \sin 30^\circ = F_{el}$

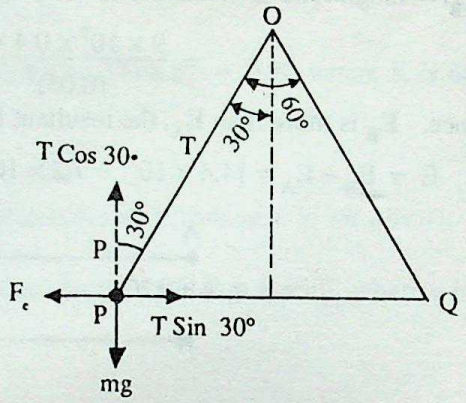
$$\therefore \quad \frac{F_{el}}{mg} = \tan 30^\circ = \frac{1}{\sqrt{3}}$$

or $$F_{el} = 0.173 \times 10^{-3} \times \frac{1}{\sqrt{3}} \times 10 = 10^{-3} \text{ N}$$

Now, $$F_{el} = \frac{9 \times 10^9 \times q^2}{(0{\cdot}5)^2} = 10^{-3}$$

or $$q^2 = \frac{25}{9} \times 10^{-14}$$

$$\therefore \quad q = \frac{5}{3} \times 10^{-7} \text{ C} = \mathbf{1.67 \times 10^{-7}\ C}$$



Example 14. *A charged simple pendulum is held in a uniform horizontal electric field E. If the pendulum gets inclined at an angle θ to the vertical, in the equilibrium position, what is the charge on its bob?*

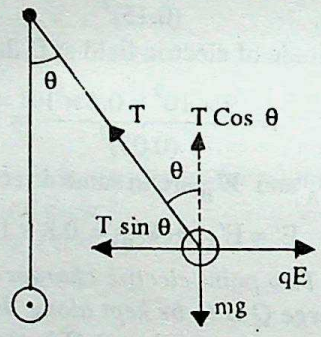
Solution : Let q be the charge on the bob. We then have, for equilibrium,

$$mg = T \cos \theta$$

and $$qE = T \sin \theta$$

$$\therefore \quad \frac{qE}{mg} = \tan \theta$$

or $$q = \left(\frac{mg \tan \theta}{E} \right)$$



Example 15. *A ball of mass 0.5 g carrying a charge of 4 μC is suspended by an insulated thread of length 50 cm. A uniform electric field of 100NC^{-1} is applied in the horizontal direction. In equilibrium what is the angle made by the thread with the vertical P.*

Solution : Fig. below shows the thread in equilibrium making an angle θ with the vertical

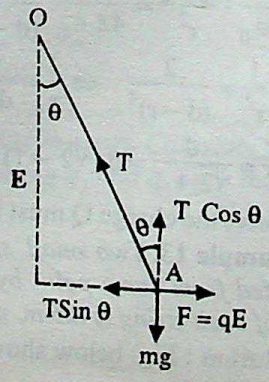
The forces acting on ball A are shown in fig. T is tension in the thread. Resolving T into its rectangular component and considering equilibrium.

$T \cos \theta = mg$ and $T \sin \theta = qE$

$\tan \theta = qE/mg$

Given $q = 4 \times 10^{-6}$ C; $m = 5 \times 10^{-4}$ kg, $E = 100$ NC^{-1}

$$\tan \theta = \frac{4 \times 10^{-6} \times 10^2}{5 \times 10^{-4} \times 10} = 0.08 \Rightarrow \theta = \tan^{-1}(0.08) = \mathbf{4.573^\circ}$$



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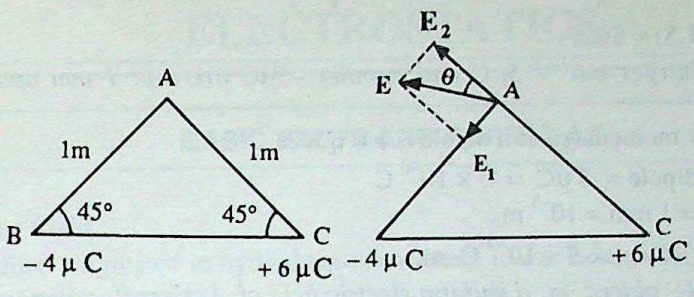
Example 16. *Charges of – 4μC and + 3μC are placed at the two corners of a right angled triangles as shown in the following figure. What is the total electric field at A due to the two charges ?*



Solution :

The electric field $\mathbf{E}_1$ at A due to charge at B is

$$E_1 = \frac{9 \times 10^9 \times 4 \times 10^{-6} \times 1^2}{(1)^2} NC^{-1} = 36 \times 10^3 \ NC^{-1}$$

Similarly, the electric field $\mathbf{E}_2$ at A due to charge at C is

$$E_2 = \frac{9 \times 10^9 \times 3 \times 10^{-6} \times 1}{(1)^2} NC^{-1} = 27 \times 10^3 \ NC^{-1}$$

The two fields $\mathbf{E}_1$ and $\mathbf{E}_2$ are at right angles to one another. The resultant E is

$$E = \sqrt{E_1^{\ 2} + E_2^{\ 2}} = \sqrt{(36)^2 + (27)^2} \times 10^3 = 45 \times 10^3 \ NC^{-1}$$

Let the resultant **E** makes an angle θ with **CA.**

$\tan \theta = E_1/E_2 = 27/36 = 0.75$, Therefore, fig. $\theta = \tan^{-1}(0.75) =$ **36.87°**

Example 17. *Charges are placed at the four corners of a square of side 1 m as shown in fig. 38 What is the electric field at O due to the charges ?*

Solution: Let $\mathbf{E}_1$, $\mathbf{E}_2$ $\mathbf{E}_3$ and $\mathbf{E}_4$ denote field at O due to charges at A, B, C and D respectively. The direction of field is as shown in the following fig.

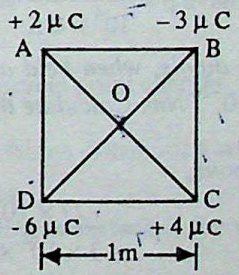
Also, $OA = OB = OC = OD = \frac{1}{\sqrt{2}}$ m. From Coulomb's law,

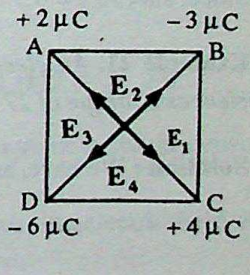
$$E_1 = \frac{9 \times 10^9 \times 2 \times 10^{-6}}{(1/\sqrt{2})^2} = 36 \times 10^3 \ NC^{-1}$$

$$E_2 = \frac{9 \times 10^9 \times 3 \times 10^{-6}}{(1/\sqrt{2})^2} = 54 \times 10^3 \ NC^{-1}$$

$$E_3 = \frac{9 \times 10^9 \times 4 \times 10^{-6}}{(1/\sqrt{2})^2} = 72 \times 10^3 \ NC^{-1}$$

$$E_4 = \frac{9 \times 10^9 \times 6 \times 10^{-6}}{(1/\sqrt{2})^2} = 108 \times 10^3 \ NC^{-1}$$





From fig, it is clear that E_1 and E_3 are oppositely directed. Their resultant, say E_x is

$E_x = E_3 - E_1 = 36 \times 10^3 \ NC^{-1}$

Similarly, the resultant of E_2 and E_4, say E_y is

$E_y = E_4 - E_2 = 54 \times 10^3 \ NC^{-1}$

Now E_x and E_y are at right angles to one another as shown in the diagram. Their resultant E is

$$E = \sqrt{E_x^{\ 2} + E_y^{\ 2}}$$

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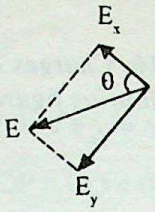
$= \sqrt{(36)^2 + (54)^2} \times 10^3 = \mathbf{64.89 \times 10^3\ NC}$



Let E make an angle θ with E_x. Obviously. $\tan\theta = E_y/E_x = 54/36 = 1.5$

Therefore, $\theta = \tan^{-1}(1.5) = \mathbf{56.3°}$.

Example 18. *Two charges one + 5μC and another –5μC are kept 1 mm apart. Calculate the dipole moment.* **(C.B.S.E. 1994)**

Solution : The dipole moment (p) of a dipole is $p = q \times 2a$

Given q = charge of dipole = $5\ \mu C = 5 \times 10^{-6}$ C

2a = length of dipole = 1 mm = 10^{-3} m

$\therefore\ p = 5 \times 10^{-6} \times 10^{-3}$ C–m = $\mathbf{5 \times 10^{-9}\ C–m}$.

Example 19. *A dipole placed in a uniform electric field of 1 V cm^{-1} experiences a torque of 0.1 N-cm when the axis of dipole makes an angle of 30° with the external field. Calculate the dipole moment.*

Solution : The couple τ experienced by a dipole of moment **p** when at angle θ with a uniform electric field E is $\tau = pE \sin\theta$

Given $\tau = 0.1$ N-cm = 10^{-3} N-m,

E = 1V cm^{-1} = 10^2 Vm^{-1}; $\theta = 30°$

$10^{-3} = p \times 10^2 \times \sin 30 = p \times 10^2/2$

$\therefore\ p = \mathbf{2 \times 10^{-5}\ C–m}$.

Example 20. *An electric dipole, when held at 30° with respect to a uniform electric field of 10^4 N/C, experiences a torque of 9×10^{-26} Nm. Calculate the dipole moment of the dipole.*

(CBSE 1996)

Solution : We know that the torque τ, on a dipole of moment p, when kept at an angle θ to an external electric field E, is given by

$$\tau = pE \sin\theta$$

$$\therefore\quad p = \frac{\tau}{E \sin\theta}$$

Here $\tau = 9 \times 10^{-26}$ N m, E = 10^4 NC^{-1} and $\theta = 30°$.

Since, $\sin(30°) = 0.5$, we have $p = \dfrac{9 \times 10^{-26}}{10^4 \times 0.5} = \mathbf{18 \times 10^{-30}\ C–m}$

Example 21. *An electric dipole, when held at an angle of 30° to a uniform electric field of 3×10^4 N/C, experiences a torque of 27×10^{-26} Nm. Calculate the dipole moment of the dipole.*

(CBSE 1996)

Solution : We have, as above,

$$p = \frac{27 \times 10^{-26}}{3 \times 10^4 \times 0.5} = \mathbf{18 \times 10^{-30}\ C–m}$$

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ELECTROSTATICS

BASIC FACTS AND FORMULAE

The 'Flux' of a Vector Field

The concept of 'flux' originated in hydrodyna-mics where it was used to imply *the rate of flow of a fluid through a given (cross sectional) area.*

The concept was soon generalized and one could think of the flux of any given vector field as the rate of *'flow'* of that vector field.

For the electric field, we can (qualitatively) think of the flux of (this) field, through a given surface, as the number of lines of force of (this) field that cross the given surface normally.

In a formal (quantitative) sense, the flux (ϕ) of **E**, through a given surface S, is defined as the *surface integral of* **E** *over the surface S i.e.,*

$$\phi = \int_s \mathbf{E} \cdot \mathbf{dS}$$

Here it is conventional to regard each elemental surface vector **dS** as having the direction of the *outward normal* to S at the location of the surface element dS. We may, also write, $\phi = \int E \, . \, dS \cos\theta$

where θ is angle between the vectors **E** and **dS**, at the location of **dS**.

Gauss's Theorem

According to *Gauss's theorem'* the (net outward) flux (ϕ) of the electric field, through any closed surface S, is equal to $(1/\epsilon_0)$ times the net charge (Q), present in the volume τ enclosed by the (closed) surface S. Thus,

$$\int_s \mathbf{E} \cdot \mathbf{dS} = \frac{1}{\epsilon_0} Q$$

The total charge Q, in the volume τ, enclosed by the closed surface S may be expressed as

$Q = \sum_{i=1}^{n} q_i$ if the enclosed charges are present as discrete point charges, and as $Q = \int_\tau \rho d\tau$

if the enclosed charges are present in τ as a 'continuous' charge distribution with a volume charge density ρ.

The 'Gaussian Surface' for a given Charge Distribution

For a given charge distribution, if we can find a (closed) surface S for which, the electric field due to the given charge distribution,

(i)is normal* to the surface at all points,

and (ii) has a constant magnitude at all points of the surface, the surface S is called the *Gaussian surface* for the given charge distribution. We can use Gauss's theorem, to find **E** for a given charge distribution, only if we can *define a Gaussian surface for that charge* distribution.

Field due to An infinite Plane Sheet

The field, due to an infinite plane sheet of charge, having a uniform surface charge density σ, is given by

* In general, it is not necessary to have a closed (Gaussian) surface S such that **E** is *normal* to it, at all points of S. We can also have a closed surface S such that (i) **E** is *normal* to it, at all points, for a part S_1 of this surface, and (ii) parallel to it, at all points for a part S_2 of this surface. We then need consider only the part S_1 for calculating the flux of **E** through the surface S.

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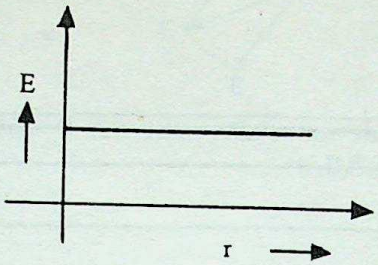
$$\mathbf{E} = \frac{\sigma}{\epsilon_0}\hat{n}$$

Where $\hat{n}$ is a unit vector along the normal to the sheet and directed away from it.



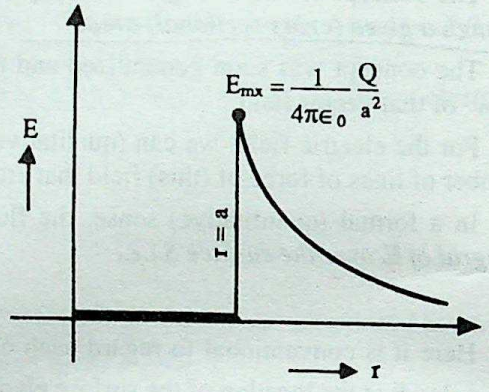
The field of an infinite plane sheet, thus, has a *constant* magnitude at all field points. We may represent this fact by the graph shown alongside. Here E is the field magnitude at a point distant r from the sheet.

Field due to a Hollow Charged Conducting Sphere

The field due to a hollow charged (total charge = Q) conducting sphere, of radius a, at a point distance r from its centre is

(*i*) *zero*, if $r < a$, i.e., if the field point is inside the sphere and

(*ii*) $\frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}$ if $r \geq a$. Thus for surface points, and for external points, the charged sphere behaves as if its total charge were concentrated, as a point charge, at its centre. These facts are graphically illustrated in the fig above.



General Properties of Conductors in Electrostatic Fields

It turns out that conductors, when kept in an electrostatic field, satisfy certain general conditions. Some of these properties are listed below :

(i) The electric field in the interior of a conductor is zero.

(ii) Any charge given to a conductor resides only on its surface, i.e., the volume density of charge inside a conductor is zero.

(iii) For points just outside the surface of the conductor, the electric field is normal to the surface, i.e., the field just outside has no tangential component.

(iv) The surface of a conductor is an equipotential surface.

(v) The magnitude of the field strength at a point on the surface of a conductor is proportional to the (surface) charge density there.

(vi) The electric field just outside the surface of a conductor , at any point P on it, is given by $\mathbf{E} = \sigma/\epsilon_0$ where σ is the surface charge density at P.

The Conservative Nature of the Electrostatic Field

The electrostatic field is a *conservative field.* This implies that the work done in carrying any charge (in this field) from any one (field) point, to any other (field) point, depends only on the coordinates of these two field points and not on the path followed.

In other words, we may say that the work done in transporting a charge, from one (field) point to another, in an electrostatic field, is (completely) *path independent.*

Electrostatic Potential Difference

The conservative nature of the electrostatic field helps us to define a scalar quantity, the *electrostatic potential* for this field.

The potential difference,$(V_B - V_A)$, between any two field points, A and B, in an electrostatic field is defined as the work done in carrying a unit (positive) test charge from A to B.

Thus, $V_B - V_A = \frac{\Delta W_{AB}}{\Delta q}$ where ΔW_{AB} is the (small) work done in carrying a (small) test charge Δq, from A to B in the given field.

The potential at a Field Point :

The potential at a given (field) point, in a given electrostatic field, *is defined (usually as the work done in carrying a unit positive charge from infinity to that (field) point.*

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This definition is based on the convention of regarding the *point at infinity* as the (common) reference point, for all other field points, where the potential (by convention) is regarded as zero.

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Relation between Potential and Field

The electric field can be calculated, from the potential, through the following relation between the two :

The component of the electric field, in any direction, is equal to the negative rate of change of potential in that direction. Thus, $E_r = -\frac{dV}{dr}$

Remembering that $\mathbf{E} = E_x \hat{i} + E_y \hat{j} + E_z \hat{k}$,

we may write

$$\mathbf{E} = -\left(\frac{\partial V}{\partial x}\hat{i} + \frac{\partial V}{\partial y}\hat{j} + \frac{\partial V}{\partial z}\hat{k}\right)$$

We can also calculate the potential difference, $V_B - V_A$, between any two field points A and B by using the relation

$$V_B - V_A = -\int_A^B \mathbf{E} \cdot d\boldsymbol{l}$$

i.e., the potential difference, between any two (field) points, is simply (negative) of the line integral of the electric field, along any line whatsoever, connecting these two field points.

Equipotential Surface

The locus of all points having the same potential, (in a given field), is defined as an equipotential region.

When we construct a surface through a given point, such that the potential, at all points of this surface has the same value as that at the point (originally) chosen, we refer to this surface as an equipotential surface (through the given point).

The following are some important properties of an equipotential surface :

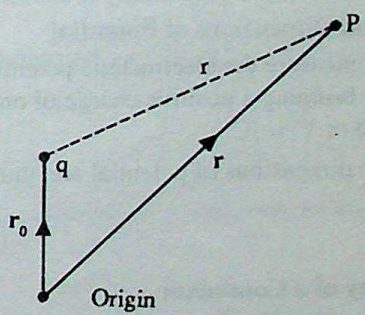
(a) No two equipotentials can intersect each other. If this were so, the point of intersection would have two values of potentials.

(b) The electric field intensity, at every point on an equipotential surface, is along the normal to the equipotential at that point.

(c) The equipotentials due to a collection of charges (whose total sum is not zero), can be approximately considered as spheres at large distances.

Potential due to a Point Charge

The potential, due to a point charge, q, at a field point, distant r from it, is given by $V(r) = \frac{1}{4\pi\epsilon_0}\frac{q}{r}$



If the location of the (source) charge q is at a point defined by the position vector $\mathbf{r}_0$, and the field point is defined by the position vector $\mathbf{r}$, we may write

$$V = \frac{1}{4\pi\epsilon_0}\frac{q}{|r - r_0|}$$

Potential due to a Collection of Charges and that due to a Continuous Charge Distribution :

The potential at a field point P, due to a collection of n point charges $q_1, q_2 \ldots q_n$, is given by

$$V = \frac{1}{4\pi\epsilon_0}\sum_{i=1}^{n}\frac{q_i}{r_i}$$

where r_i is the distance of the field point P from the charge q_i.

For a continuous charge distribution, the potential is given by

$$V = \frac{1}{4\pi\epsilon_0}\int\frac{dq}{r}$$

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where r is the distance of the field point from the elemental charge dq and the integration is to be carried over the whole charge distribution.

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Potential due to a Dipole

The potential at an *axial* point of a dipole of moment **p**, is given by

$$V = \frac{p}{4\pi\epsilon_0 (x^2 - a^2)}$$

For all *equatorial* points, the potential of a dipole, is simply zero.

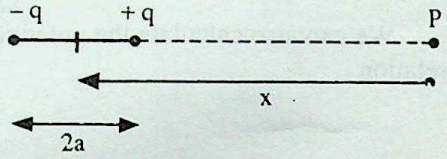
For a small dipole, or for very far off points, (x >> a), the potential at axial points, is (nearly)

$$V \approx \frac{1}{4\pi\epsilon_0} \frac{p}{x^2}$$

It is important to note that the potential due to a

(i) point charge varies as $\frac{1}{r}$

and (ii) dipole varies as $\frac{1}{r^2}$



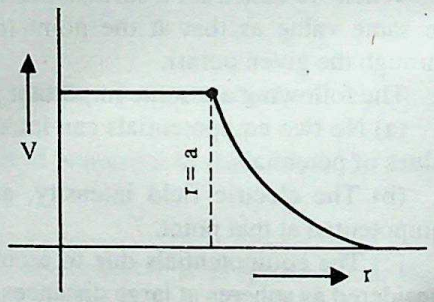
The corresponding variations of the electric field are as $\frac{1}{r^2}$ and $\frac{1}{r^3}$ i.e, one order higher than those of the potential.

Potential due to a Charged Conducting Sphere

The potential due to a charged (total charge = Q) conducting sphere of radius a, at any field point, distant r from its centre, equals

(i) $\frac{1}{4\pi\epsilon_0} \frac{Q}{a}$ for $r \leq a$

and (ii) $\frac{1}{4\pi\epsilon_0} \frac{Q}{r}$ for $r \geq a$



These facts are graphically illustrated in the above fig.

Units and Dimensions of Potential

We measure the electrostatic potential in units of the *volt* (V). The potential at a point is one volt if the work done, in bringing a positive charge of one coulomb, from infinity to that point , is one joule. Thus, Volt = Joule / coulomb or $V = JC^{-1}$

The dimensions of potential are, thus, clearly

$$[V] = \frac{ML^2T^{-2}}{AT} = ML^2T^{-3}A^{-1}$$

Capacity of a Conductor

The capacity of a conductor is a measure of its ability to 'store' charge. Let Q be the charge given to a conductor and V its (resulting) surface potential. The ratio Q/V, i.e., the charge needed to cause a unit potential on the surface of the conductor, is known as the capacitance (C) of the conductor. Thus,

$$C = Q/V$$

The capacitance (or capacity) of a conductor is a characteristic of the shape and size of the conductor but is independent of the nature of its material. It is thus, a constant characteristic of the geometry of the conductor.

Units and Dimensions of Capacitance

Since C = Q/V, the SI unit of capacitance is clearly coulomb/volt or CV^{-1}. This unit has been given the name *farad* (F).

Thus, farad = coulomb /volt or $F = CV^{-1}$

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A conductor is thus said to have a capacitance of one farad if it acquires a potential of one volt when one coulomb of charge is put on it.

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The farad is a very large unit of capacitance and, in practice, capacitance values in its submultiples only, are encountered.

1 millifarad (= 1 mF) = 10^{-3} F
1 microfarad (=1 μF) = 10^{-6} F
1 nanofarad (= 1 nF) = 10^{-9} F
1 picofarad (= 1pF) = 10^{-12} F

The dimensions of C are

$$[C] = \frac{[\text{Charge}]}{[\text{Potential}]} = \frac{AT}{ML^2T^{-3}A^{-1}} = M^{-1}L^{-2}T^4A^2$$

Capacitance of a Spherical Conductor

The capacitance of a spherical conductor, of radius a, is given by

$$C = 4\pi\epsilon_0 a$$

$$C \approx \frac{1}{9 \times 10^9} a$$

We would, thus, need a sphere of radius 9×10^9 m to get a capacitance of one farad. It follows that the capacitance of ordinary conductors is going to be very very small indeed !

The Capacitor

A system of two conductors, carrying equal and opposite charges (+Q and –Q), and separated by (usually a very small) distance is known as a *capacitor.* The capacitance of capacitors, even of quite small size, can be made reasonably large.

The Capacitance of a Capacitor

The capacitance (C) of a capacitor is defined as the ratio of the magnitude of charge (Q), on either of its conductors, to the (resulting) potential difference (V) between them. Thus

$$C = Q/V$$

when the two conductors, carrying charges + Q and –Q, have a *potential difference* V between them due to these two (equal and opposite) charges.

The parallel plate capacitor :

This is the most common type of capacitor and consists of two parallel conducting plates, kept a small distance apart. The capacitance C of a parallel plate capacitor is given by

$$C = \frac{\epsilon_0 A}{d}$$

when the two plates are separated by vacuum. If, however, the plates are separated by a dielectric of relative permittivity (dielectric constant) ϵ_r, the capacitance is given by

$$C = \epsilon_0 \epsilon_r \frac{A}{d}$$

Here A is the area of either of the two plates and 'd' is their mutual distance of separation.

The Spherical and the Cylindrical Capacitors

These consist of two concentric (or co-axial) spheres (or cylinders) of radius a and b respectively, with the outer sphere (or cylinder) earthed. The capacitance is given by

$$C_{\text{sphere}} = 4\pi\epsilon_0 \frac{ab}{(b-a)} \quad C_{\text{cylindrical}} = \frac{2\pi\epsilon_0}{\log_e (b/a)}, \text{ (per unit length)}$$

These values of capacitance get multiplied by a factor ϵ_r when the spheres (or cylinders) are separated by a dielectric of relative permittivity ϵ_r.

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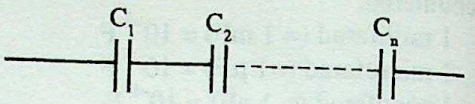
Series Combination of Capacitors

When n capacitors of capacitance $C_1, C_2, C_3 \ldots\ldots C_n$ are connected *in series*, their equivalent capacitance, C_s is given by

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots\ldots + \frac{1}{C_n} = \sum_{i=1}^{n} \frac{1}{C_i}$$

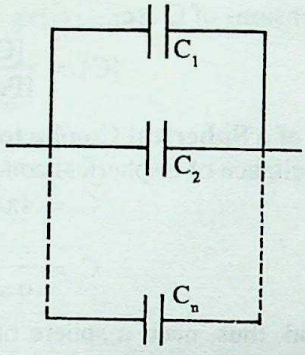


The equivalent capacitance of the series combination is thus smaller than the smallest of the individual capacitors.

Parallel Combination of Capacitors

When n capacitors, of capacitance $C_1, C_2 \ldots\ldots C_n$, are connected in parallel, their equivalent capacitance, C_p, is given by

$$C_p = C_1 + C_2 + \ldots\ldots + C_n = \sum_{i=1}^{n} C_i$$



The equivalent capacitance, in this case, is, thus, larger than the largest of the individual capacitances.

Energy Stored in a Charged Capacitor

Let a capacitor of capacitance C, have charges + Q and –Q on its two plates, and let the resulting potential difference between them be V. The capacitor then has an energy E stored in it where

$$E = \frac{1}{2} CV^2 = \frac{1}{2} \frac{Q^2}{C} = \frac{1}{2} QV$$

Energy Density of the Electric Field

Whenever any charge configuration causes an electric field in a region of space, we may regard this electric field as a 'seat' of energy. The *energy density* (E_d) (energy per unit volume of the space having the electric field) of the electric field is given by

$$E_d = \frac{1}{2} \epsilon_0 E^2$$

The units of E_d are clearly joule / metre ^{3} or Jm^{-3}.

Van de Graff Generator

The Van de Graff generator is a man made high voltage machine that can enable us to attain voltages of the order of 10 million volts. It can be used for a variety of experiments and applications in nuclear physics.

SUBJECTIVE QUESTIONS ON UNIT - IB

Q.1. *Define 'electric flux' through a surface.* (1)

Ans. The 'electric flux' through a given surface, equals the surface integral of the electric field over that surface. Thus, $\phi = \int_S \mathbf{E} \cdot \mathbf{ds}$

We may interpret the 'electric flux' as

(i) the rate of 'flow' of the electric field through the given surface,

or (ii)the number of c lines of force' of the electric field crossing normally across the given surface.

Q.2. *What is meant by 'positive flux' ?* (1)

Ans. We speak of the 'flux' as *positive* when there is a net outward 'flow'of the lines of force of the electric field, through the given surface.

Q.3. *What is meant by 'negative flux' ?* (1)

Ans. We speak of the 'flux' as *negative* when there is a net inward 'flow' of the lines of force, of the electric field through the given surface.

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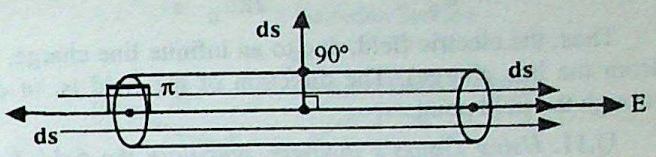
Q.4. *How do we relate the total number of lines of force, emanating from a charged object, with the flux of its electric field through a closed surface, enclosing the charged object ?* **(1)**

Ans. It is usual to draw the lines of force in such a way that their total number, crossing normally through the given (closed) surface, equals the (net) flux of the electric field through that (closed) surface.

Q.5. *What is the flux of a given uniform electric field through a closed cylinder of length L and uniform circular cross sectional area A ? The given uniform field is directed parallel to the axis of the cylinder.* **(2)**

Ans. The lines of force of the electric field, here are 'normal' only to the two end caps (each of area = A) of the cylinder but are parallel to its curved surface.



Hence

$$\phi = \int_{\text{curved surface}} \mathbf{E}\cdot\mathbf{ds} + \int_{\text{end caps}} \mathbf{E}\cdot\mathbf{ds}$$

$$= \int_{\text{curved surface}} E\,ds\cos 90^\circ + \int_A E\,ds\cos 0^\circ + \int_A E\,ds\cos\pi$$

$$= +\,EA + (-EA) = 0$$

Hence, the net flux of **E** through the closed cylinder in zero.

Q.6. *State Gauss's theorem in electrostatics.* **(1)**

Ans. The (net outward) flux of the electric field through a given closed surface (S) is equal to $(1/\epsilon_0)$ times the net charge (Q) present in the volume *t* enclosed by the surface S. Thus,

$$\int_S \mathbf{E}\cdot\mathbf{ds} = \frac{1}{\epsilon_0}\,Q$$

Q.7. *What do you understand by the 'Gaussian surface' for a given charge distribution ?* **(2)**

Ans. A 'Gaussian Surface', for a given 'charge distribution', is a closed surface, enclosing that charge distribution, such that the electric field, due to that charge distribution (i) is everywhere normal to all points of that closed surface (or in general, the electric field is normal to some parts of that closed surface and parallel to the remaining parts of that closed surface), (ii) has a constant magnitude at all points of that closed surface.

Q.8. *From a physical point of view, we may say that Gauss's law and Coulomb's law compliment each other. Is this statement true ?* **(1)**

Ans. Yes. Gauss's law is a consequence of the 'inverse square variation' (with distance) of the electrostatic force between two point charges. This is what Coulomb's law states.

Incidently, one can also easily 'derive' Coulomb's law from Gauss's law.

Q.9. *If Coulomb's law were to involve a* $\frac{1}{r^3}$ *dependence (rather than the known* $\frac{1}{r^2}$ *dependence), for the electrostatic force between two point charges, would Gauss's law be still true ?* **(1)**

Ans. No. Gauss's law is a consequence of the inverse square nature of Coulomb's law and would not hold if there was a $\frac{1}{r^3}$ (or any other power except $\frac{1}{r^2}$) dependence of the electrostatic force between two point charges.

Q.10. *Using Gauss's theorem, calculate the field due to an infinite line of charge, having a uniform linear charge density* λ *at all points.* **(3)**

Ans. The field of an infinite line charge is known to be normal to the line charge at all points.

We take a cylinder (with the line charge as axis) passing through the given field point and close its two ends with 'end caps' (shown shaded). This is the Gaussian surface for the given charge distribution. The flux of the electric field, through the cylinder, is

$$\phi = \int_{\text{cylinder}} \mathbf{E}\cdot\mathbf{ds} = \int_{\text{curved surface}} \mathbf{E}\cdot\mathbf{ds} + \int_{\text{End caps}} \mathbf{E}\cdot\mathbf{ds}$$

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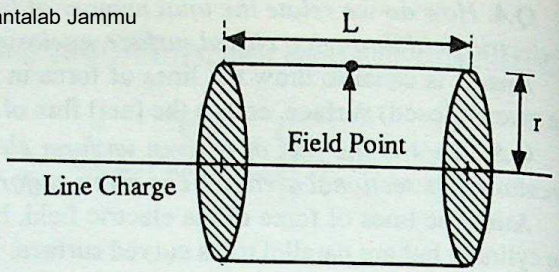
$$= \int_{2\pi rL} E\,dr\cos 0^\circ + \int_{2\times\pi r^2} E\,dr\cos 90^\circ$$

$$= E \cdot 2\pi rl + 0 = E\,2\pi rl$$

By Gauss's theorem, this must equal $\lambda l/\epsilon_0$ (as the enclosed charge is λl). Hence

$$E \cdot 2\pi rl = \frac{\lambda l}{\epsilon_0} \quad \text{or} \quad E = \frac{1}{2\pi\epsilon_0}\,\frac{\lambda}{r}$$



Thus, the electric field, due to an infinite line charge, varies as the inverse of the distance of the field point (from the line charge). The direction of the field is, of course, along the normal to the line charge, passing through the field point.

Q.11. *Using Gauss's theorem, calculate the field due to a thin plane infinite sheet of charge, having a uniform surface charge density* σ. (3)

Ans. The field of an infinite plane sheet of charge is along the normal to the sheet.

We draw a closed cylinder, passing through the sheet (as shown) as the Gaussian surface, for the given charge distribution. The field is normal to the 'end caps' of this cylinder and parallel to its curved surface. Hence the flux (ϕ) of the electric field, through this cylinder, is

$$\phi = \int \mathbf{E}\cdot\mathbf{ds} = \int_{\text{End caps}} \mathbf{E}\cdot\mathbf{ds} + \int_{\substack{\text{curved}\\ \text{surface}}} \mathbf{E}\cdot\mathbf{ds}$$

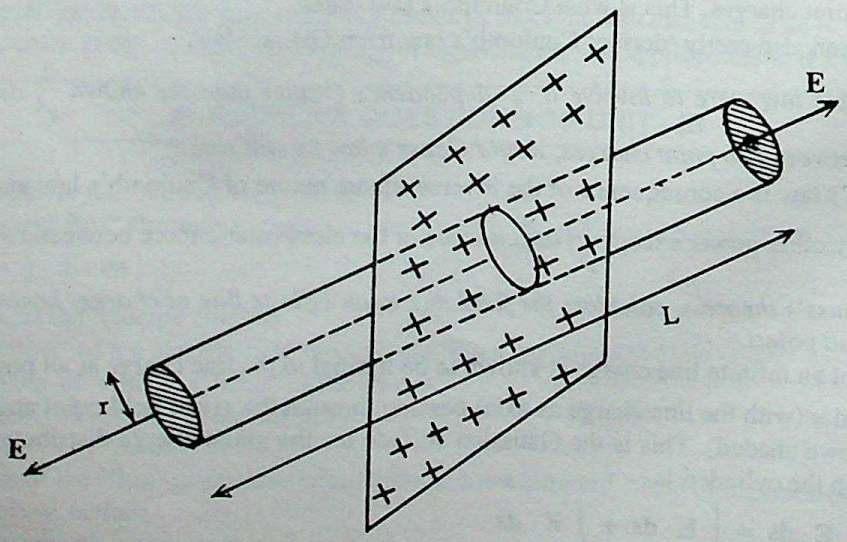
$$= \int_{2\times\pi r^2} E\,dr\cos 0^\circ + \int_{2\pi rl} E\,dr\cos 90^\circ = E\times 2\pi r^2 + 0 = 2\pi r^2 E$$

By Gauss's theorem, this must equal $1/\epsilon_0$ times the 'enclosed charge'. The enclosed charge equals $\sigma\times\pi r^2$ as the area of the sheet, enclosed by the Gaussian surface considered, is only πr^2. Hence,

$$2\pi r^2\, E = \sigma\cdot\pi r^2/\epsilon_0$$

$\therefore$

$$E = \sigma/2\epsilon_0$$



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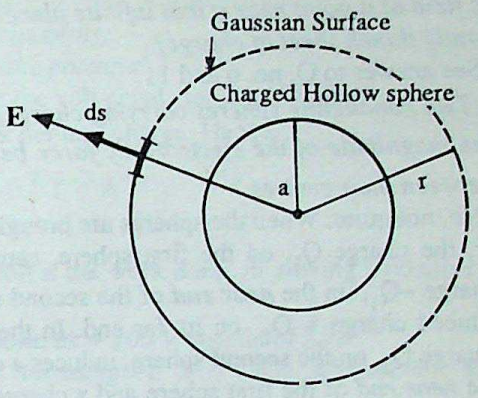
The field of an infinite plane sheet of charge is, thus, a field of *constant magnitude* directed along the normal to the sheet passing through the field point.

Q.12. *Show that, for a point outside, a uniformly charged hollow sphere behaves as if its entire charge were concentrated at its centre.* **(3)**

Ans. Because of the spherical symmetry, we can take concentric sphere, passing through the field point, as the Gaussian's surface for this problem. The flux of **E** through this surface is

$$\phi = \int \mathbf{E} \cdot \mathbf{dr} = \int_{4\pi r^2} E.dr \cos 0^\circ = E \cdot 4\pi r^2$$

This must equal $1/\epsilon_0$ times the enclosed charge. The enclosed charge is the total charge, Q, on the given charged hollow sphere. Hence,



$$E \cdot 4\pi r^2 = \frac{1}{\epsilon_0} Q$$

or
$$E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$$

This is also the value of E for a point charge Q located at the centre of the sphere. Hence, for external points, the charged hollow sphere behaves as if its entire charge were concentrated at its centre.

Q.13. *State Gauss's theorem in electrostatics. Apply this to calculate the field intensity at a point near an infinite plane sheet of charge.* **(3)**

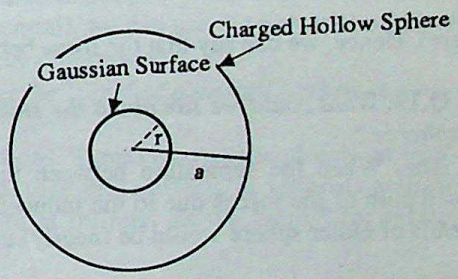
(CBSE 1995 Comptt)

Ans. See answers to Q.no. 6 and Q. no. 11 above.

Q.14. *Show that for a uniformly charged hollow sphere, the electric field has a maximum value at the surface of the sphere.* **(3)**

Ans. We have seen above Q.no. 12 that, for outside points, the charged hollow sphere behaves as if its entire charge, Q, were concentrated as a point charge at its centre.

Let us now obtain the value of the field at an internal point (r < a) of the sphere. For the concentric sphere of radius r now (the Gaussian surface) the enclosed charge is zero. Hence, by Gauss's theorem.



$$\int \mathbf{E} \cdot \mathbf{ds} = \frac{0}{\epsilon_0} = 0$$

$$\therefore \quad \int E ds \cos 0^\circ = 0$$

or
$$E = 0$$

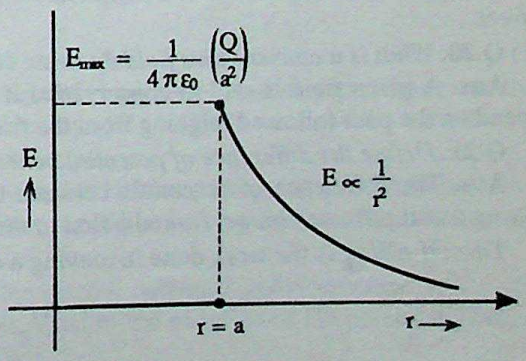
Thus, the electric field is zero at all internal points.

We, thus, have

$E = 0$ for all $r < a$.

and $E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$ for all $r \geq a$.

The field, at the surface is, thus, $\frac{1}{4\pi\epsilon_0} \frac{Q}{a^2}$ and it falls off as $1/r^2$ for outside points. The field therefore, has its maximum value at the surface of the sphere. This is illustrated graphically in fig. above.



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Q.15. *State Gauss's theorem in electrostatic. Apply this theorem to calculate the electric field inside a hollow conducting spheres.* **(C.B.S.E. 1995 Comptt)** (3)

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Ans. See answers to Q. No. 6 and Q. No. 14 above.

Q.16. *State Gauss's theorem. Using Gauss's theorem, derive an expression for electric field intensity at any point inside a hollow charged conducting sphere.* **(C.B.S.E. 1997)** (3)

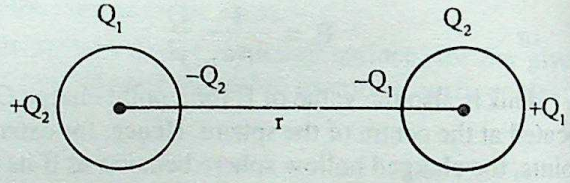
Ans. See answers to Q. no. 15.

Q.17. *State Gauss's theorem in electrostatics and express it mathematically. Using it, derive an expression for electric field at a point near a thin infinite place sheet of electric change. How does this electric field change for a uniformly thinck sheet of charge?* **(C.B.S.E. 1998, 99)** (5)

Ans. See answer to Q. no. 6 and 11.

Q.18. *Two conducting spheres carrying charges Q_1 and Q_2, are brought close to each other. Is it correct to say that the magnitude of the electrostatic force between them is exactly given by $Q_1 Q_2/4\pi\epsilon_0 r^2$), where r is distance between their centres ?* (3)

Ans. No, not quite. When the spheres are brought near each other, the charge Q_1, on the first sphere, causes an induced charge $-Q_1$, on the *near end* of the second sphere and an induced charge $+ Q_1$ on its far end. In the same way, the charge Q_2, on the second sphere, induces a charge $- Q_2$ on the *near end* of the first sphere and a charge $+ Q_2$ on its *far end*. The attractive and repulsive forces on each sphere, due to these induced charges do not quite cancel each other because the charge induced on the near end is a bit nearer to the other sphere than the charge induced on the opposite end. The attractive forces between the two spheres, due to the induced charges are a little stronger than the repulsive forces and there is, thus, a net attractive forces (between the spheres) due to the (mutually) induced charges. This force is, over and above, the force $\left(\frac{1}{4\pi\epsilon_0}\right)\frac{Q_1 Q_2}{r^2}$ which the two spheres exert on each other (we must remember that, for outside points, a charged sphere behaves like a point charge, with the (equivalent) point charge located at the centre of the sphere). Hence, we can say that the force between the spheres is not *exactly* given by $\frac{1}{4\pi\epsilon_0}\frac{Q_1 Q_2}{r^2}$



Q.19. *What could we say about the statement of Q.no. 17 if r were very large in comparison to the radii of the spheres ?* (1)

Ans. When the separation between the spheres is very large, in comparison to their radii, the mutual cancellation of the forces due to the induced charges would be (almost) complete. This is because the near and far ends of either sphere would be (nearly) at equal distances, from the centre of the other sphere. We could then say that the statement (namely the force between the two sphere is *exactly* given by $\frac{1}{4\pi\epsilon_0}\frac{Q_1 Q_2}{r^2}$) is (almost) correct.

Q.20. *What is a conservative field ?* (1)

Ans. A given field is said to conservative if its line integral, between any two points in the field, does not depend on the path followed in going from the first to the second point.

Q.21. *Define the difference of potential between two points in a given electrostatic field.* (1)

Ans. The difference of potentials between two points, in a given electrostatic field, is the work done in moving a unit positive charge, from the first to the second point, via any path whatsoever.

Thus, if ΔW_{AB} is the work done in moving a charge Δq, from the point A to the point B, we have

$$V_B - V_A = \frac{(\Delta W_{AB})}{(\Delta q)}$$

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Q.22. *Define electric potential. Is it a scalar or a vector quantity ?* **(CBSE 1993 Comptt.) (1)**

Ans. The electric potential, at a given point , in an electrostatic field, is (usually) defined as the work done in moving a unit positive charge, from infinity to that point, via any path whatsoever.

Thus, if $\Delta W_{\infty P}$ is the work done in moving a charge Δq from ∞ to point P, we have

$$V_p = \frac{\Delta W_{\infty p}}{(\Delta q)}$$

Electric potential, being work per unit charge, is a *scalar quantity.*

Q.23. *What are the units and dimensions of the electrostatic potential ?* **(2)**

Ans. Electric potential is measured in units of volt where the volt equals joule/coulomb

The dimensions of electric potential equal to that of work per unit charge. Hence,

$$[V] = \frac{ML^2 T^{-2}}{AT} = ML^2 T^{-3} A^{-1}$$

Q.24. *Define the 'volt'.* **(1)**

Ans. The electric potential at a point, is said to be one volt if the work done, in moving a positive charge of one coulomb from infinity to that point, is one joule.

Q.25. *Are we free to call the potential of our reference point as + 100 V instead of zero?* **(1)**

Ans. Yes. The potential of the reference point can be assigned any value whatsoever, as per the requirements of the situation.

Q.26. *Does the value of the (a) potential (b) potential difference, depend on the choice of the reference point or the 'zero' of potential ?* **(1)**

Ans. The value of the

(a) potential does depend on the choice of the reference point or 'zero' of the potential.

(b) potential difference *does not* depend on the choice of the reference point or the 'zero' of potential.

Q.27. *Why do we often regard the potential of the earth to be 'zero' ?* **(1)**

Ans. The earth is a very large 'conductor'. from our ordinary point of view. Hence addition or removal, of small amounts of charges, would not affect its potential in any significant manner. We can then treat its potential to remain (practically) constant. Because of this constancy (of its potential), we can use the potential of the earth as a convenient reference (or 'zero' of potential) of potential, for practical purposes.

Q.28. *Why is it convenient to usually take the point at infinity as the 'zero' of potential? When can we not make this choice ?* **(2)**

Ans. We, usually have to deal with 'finite sized' charge distributions. Their electrostatic effects, at very far off (or at infinity) points are, therefore, negligible.We can therefore, take these effects as (almost) zero. It is, therefore, (theortically) convenient to take the potential of the 'point at infinity' as the 'zero ' (or reference value) of potential.

When, however, we are talking of the effects of an infinite charge distribution, we obviously cannot take the point as the 'zero' of potential. In such cases, we choose a convenient, (nearer home) point, as the 'zero' of potential

Q.29. *What is meant by 'potential gradient' ? Will it have the same units as potential ?* **(1)**

Ans. The potential gradient, in a given direction, equals the rate of change of potential with distance, in that direction. Thus, the potential gradient, along the x-axis, say, is given by $\Delta V/\Delta x$ Here we may take the values of the potentials, at points x and $x + \Delta x$, to be V and $V + \Delta V$ respectively.

Since potential gradient equals potential difference per unit distance, its units are going to be different from those of potential itself. In fact, the SI unit of the potential gradient, would be *volt per metre.* (These incidently, are the units of the electric field)

Q.30. *Explain how we may calculate the electric field from the electric potential and vice-versa.* **(2)**

Ans. The component of the electric field, in any direction is equal to the negative of the potential gradient (rate of change of potential with distance) along that direction. Thus,

$$E_r = -\Delta V/\Delta r \text{ or } -dV/dr$$

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In particular, then

$$E_x = -\frac{\partial V}{\partial x},\ E_y = -\frac{\partial V}{\partial y},\ E_z = -\frac{\partial V}{\partial z}$$

We thus, have $\mathbf{E} = E_x \hat{i} + E_y \hat{j} + E_z \hat{k}$

$$= -\left[\frac{\partial V}{\partial x}\hat{i} + \frac{\partial V}{\partial y}\hat{j} + \frac{\partial V}{\partial Z}\hat{k}\right]$$

We may use this relation to calculate the electric field from the electric potential. From above, we can also write,

$$-\Delta V = E_r \Delta r = \mathbf{E} \cdot \Delta \mathbf{r}$$

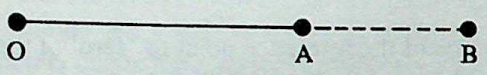
$$\therefore \quad \int_A^B \Delta V = -\int_A^B \mathbf{E} \cdot \Delta \mathbf{r}$$

$$\text{or} \quad V_B - V_A = -\int_A^B \mathbf{E} \cdot \Delta \mathbf{r}$$

Thus, the difference of potential $(V_B - V_A)$, between two given points A and B, equals the negative of the line integral of the electric field, along any line from the first to the second point

The *potential* at a point, say P, would then be the negative of the line integral of the electric field, along any line, drawn from the point at infinity to the (field) point P.

Q.31. *A point charge q is placed at O, as shown. Is $V_A - V_B$ positive, negative or zero if q is a (i) positive (ii) negative charge ?* (2)



Ans. Let r_A and r_B be the distances of points A and B from O. We then have

$$V_A = \frac{1}{4\pi\epsilon_0}\frac{q}{r_A} \text{ and } V_B = \frac{1}{4\pi\epsilon_0}\frac{q}{r_B}$$

$$\therefore \quad V_A - V_B = \frac{q}{4\pi\epsilon_0}\left(\frac{1}{r_A} - \frac{1}{R_B}\right)$$

Since, $r_A < r_B$, we have $\frac{1}{r_A} > \frac{1}{r_B}$. Hence, the term in parenthesis, is necessarily positive. It follows that (i) $(V_A - V_B)$ is positive if q is a positive charge. (ii) $(V_A - V_B)$ is negative if q is a negative charge.

Q.32. *What is the value of potential at any point on the equatorial line of an electric dipole ?* (1)

Ans. The potential, at any point on the equatorial line of a dipole, is *zero.*

Q.33. *If the electrostatic potential is constant in a given region of space. what can we say about the electric field in that region ?* (1)

Ans. The electric field, in that region, is zero. When potential is constant, the potential gradient (rate of change of potential with distance) and hence the electric field, are necessarily zero.

Q.34. *Is the electrostatic potential necessarily zero at a point where the electric field strength is zero ? Give an example to illustrate your answer.* (2)

Ans. No. The potential need only have a constant value in that region.

For example, the electric field inside a hollow charged sphere, is zero. The potential, howerver, is constant at all these internal points and has the same value as the potential on the surface of the sphere.

Q.35. *Is the electrostatic field necessarily zero at a point where the electrostatic potential is zero ? Give an example to illustrate your answer.* (2)

Ans. No. The component of the electric field in any direction is equal to the *rate of change of potential* in that direction and not to the *potential* itself. The former can be non-zero even if the latter is zero.

For example, the potential, at all points, on the equitorial line of a dipole is zero. However, the electric field is not zero at these points.

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Q.36. *State whether the direction of an electrostatic field is along that of the rise or the fall of electrostatic potential.* **(1)**

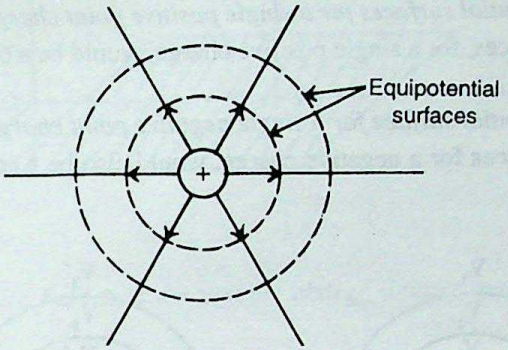
Ans. The direction of the electrostatic field is along that of the *fall* of potential, i.e., *from* a higher potential point to a lower potential point.

Q.37. *What is an equipotential surface ?* **(1)**

Ans. An equipotential surface is the locus of all points at which the potential (due to a given charge distribution) has the same value.

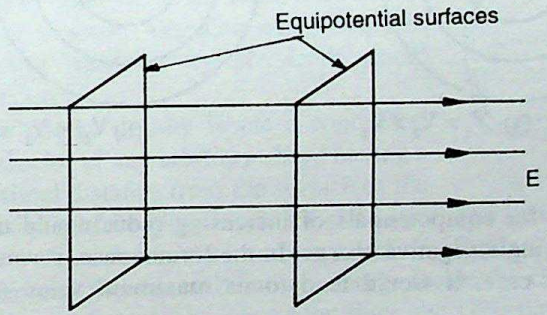
Q.38. *Sketch two equipotential surfaces for a point charge.* **(CBSE 1997) (1)**

Ans.



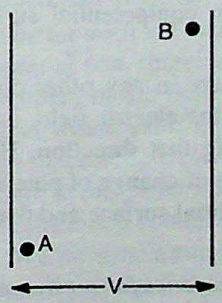
Q.39. *Draw an equipotential surface in a uniform electric field. How does the force between two points charges change if the dielectric constant of the medium in which they are kept inicreases?* **(C.B.S.E. 1999) (1)**

Ans.



The force between the two points charges decreases.

Q.40. *Two proton A and B are placed between two parallel places having a potential difference V as shown in the figure will these protons experience equal or unequal force?* **(1) (CBSE 1998)**



Ans. Protons A and B will experience the same force.

Q.41. *What is the work done in moving a charge of 10 nC between two points on an equipotential surface?* **(CBSE 1996) (1)**

Ans. Zero. (The work done equals the charge times, the potential difference between the two points considered. The latter quantity is zero, for all pairs of points, on an equipotential surface)

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Q.42. *What is the work done in moving a charge of 10nC between two points on an equipotential surface?* **(CBSE 1996)** (1)

Ans. Zero, as explained above.

Q.43. *Can two equipotential surfaces intersect ? Give reason for your answer.* (1)

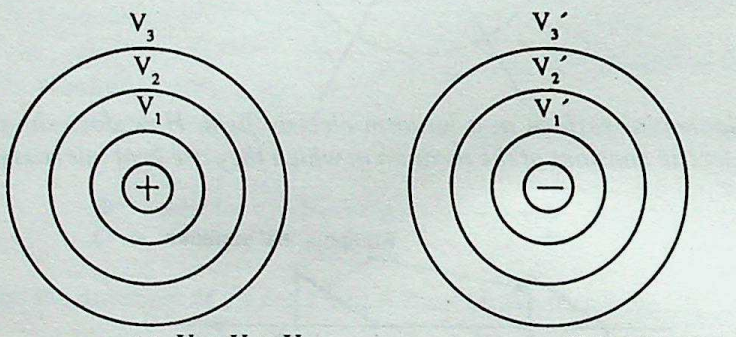
Ans. No. If two equipotential surfaces were to intersect, the potential, at the point of intersection, could have any of the two values corresponding to the two (different) equipotentials. Thus, we could have a situation where the potential at a given point could be ambigious as it could have *any of the two* values. This is physically not permissible.

Q.44. *What are the equipotential surfaces for a single positive point charge ?* (1)

Ans. The equipotential surfaces, for a single positive charge, would be a collection of concentric spheres, all centered at the positive charge.

Q.45. *What are the equipotential surface for a single negative point charge ?* (1)

Ans. The equipotential surfaces for a negative charge, would also be a collection of concentric spheres, all centered at the negative charge.



(a) $V_1 > V_2 > V_3$ (b) $V_1' < V_2' < V_3'$

(The value of the potential, for equipotentials of increasing radii, would *decrease* for a single positive charge but would *increase* for a single negative charge. In the former case, it would tend to its minimum value (equal to zero) and in the later case, it would tend to its maximum value (again equal to zero) for the equipotential sphere at infinity.

Equipotentials for a single (a) positive (b) negative charge.

Q.46. *What can we say about the direction of the electric field at all points of a equipotential surface ? Give reason for your answer.* (2)

Ans. The electric field, at all points, on an equipotential surface, is *directed along the normal* to the equipotential at that point.

This must be so, for, if the electric field were in any other direction, it would have a (finite, non-zero) component along the surface. The component of the electric field, in any direction, is known to be equal to the negative of the rate of change of potential along that direction. Hence, if the electric field were to have a component along an equipotential surface, the rate of change of potential, along it, must be non-zero. This would require the potential to change along the equipotential surface and that would contradict the very definition of an equipotential surface.

Q.47. *What is the shape of the equipotential surfaces for a given point charge ?* **(CBSE 1995)** (1)

Ans. The equipotential surfaces, for a point charge, are concentric spheres centered at the location of the point charge itself.

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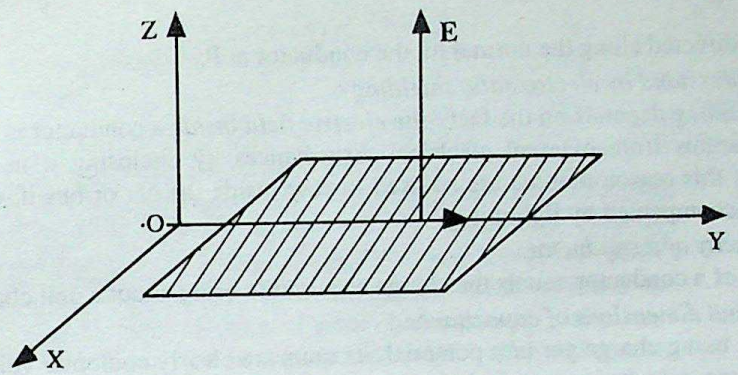
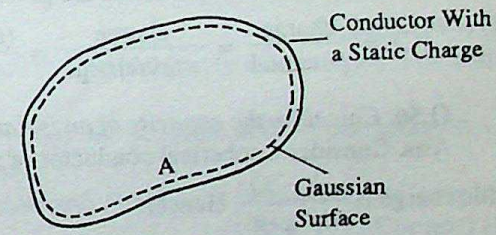
Q.48. *What is the equipotential surface corresponding to a constant electric field in the z-direction?* **(1)**

Ans. The equipotential surface and the electric field are known to be mutually perpendicular to each other. Hence, for a constant electric field, along the Z-direction, the equipotential surfaces are (equidistant) planes, parallel to the XY plane.



Q.49. *Prove that the electric field and the volume charge density must both vanish inside a conductor, under static conditions.* **(3)**

Ans. Let us imagine that there is an electric field present in the interior of a conductor. This field would then exert a force on the free electrons and would, thus, cause them to move (preferentially) in the direction opposite to the field. This would go against the assumption of a 'static' situation which requires the (microscopic), net charge inside every physically small element to remain constant in time.



To see that the volume charge density inside a conductor, vanishes, we consider a conductor of any arbitrary shape having a static charge. At an infinitesimal distance from the surface of the conductor, construct a Gaussian surface lying inside the conductor. The flux through this Gaussian surface must be zero since E is zero everywhere inside the conductor and on all ponts on the Gaussian surface. Hence, in accordance with Gauss's theorem, there must be no net charge inside the Gaussian surface. This shows that all the net charge must be on the surface of the conductor since the Gaussian surface is within an infinitesimal distance of the surface. Thus, under static conditions, there can be no net charge inside a conducting body and all the charge must reside on its surface.

Q.50. *Show that any charge, given to a conductor, can reside only on its surface.* **(2)**

Ans. Please see the answer to the second part of Q. no. 49 above.

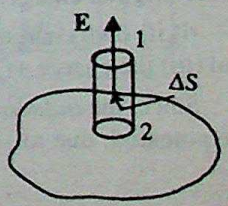
Q.51. *Show that the surface of a conductor must necessarily be an equipotential surface.* **(2)**

Ans. If the surface is not an equipotential one, there would be a change in the potential along the surface. Hence, there would be a tangential component of the field along the surface. This however, is not permissible because a tangential component, if existent would exert a net force on the surface electrons. This again would not let the conductor have a 'static' charge macroscopic configuration.

Q.52. *Obtain an expression for the field at any point just outside the surface of a conductor.* **(2)**

Ans. Consider a point P just on the surface of a conductor and imagine a small surface element Δs around it. The field at P is along the normal to ΔS. We imagine a small cylinder, of cross section ΔS extending just outside and just inside the conductor, as the Gaussian surface. We then have, by Gauss's theorem,

$$\underset{\text{Cylinder}}{\int} \mathbf{E}\cdot d\mathbf{S} = \underset{\text{End Cap 1}}{\int} \mathbf{E}\cdot d\mathbf{S} + \underset{\text{End cap 2}}{\int} \mathbf{E}\cdot d\mathbf{S} + \underset{\text{curved surface}}{\int} \mathbf{E}\cdot d\mathbf{S}$$



The latter two integrals both vanish as

(i) E is zero inside the conductor and

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(ii) E is perpendicular to dS over the curved surface. Hence,

$$\int E \cdot dS = E\Delta S$$

By Gauss's theorem, this equals $\sigma\Delta S/\epsilon_0$ since the enclosed charge is only $\sigma\Delta S$. Hence

$$E\,\Delta S = \frac{\sigma\Delta S}{\epsilon_0} \quad \text{or} \quad E = \frac{\sigma}{\epsilon_0}$$

The field is of course directed along the normal to, the conductor at P.

Q.53. *What do you understand by electrostatic shielding?* (2)

Ans. Electrostatic sheilding depends on the fact : *the electric field inside* a conductor is zero. We can protect or 'screen' sensitive apparatus from external electrical disturbances by enclosing it in a (grounded) metal conductor. It is because of this reason that we are advised to stay inside the car or bus if, on a journey, we get caught in a thunderstorm accompanied by lightining.

Q.54. *Define the capacity of a conductor.* (1)

Ans. The capacitance of a conductor equals the charge required to bring about a unit change in its potential.

Q.55. *State the units and dimensions of capacitance.* (1)

Ans. The capacitance, being charge per unit potential, its units are clearly coulomb/ volt. This unit has been named as the *farad*. Thus, capacitance is measured in units of *farad* where

$$\text{farad} = \frac{\text{coulomb}}{\text{volt}} \quad \text{or} \quad F = CV^{-1}$$

The dimensions of capacitance are given by

$$[C] = \frac{\text{charge}}{\text{potential}} = \frac{\text{charge}}{\text{work/charge}} = \frac{(\text{charge})^2}{\text{work}} = \frac{(AT)^2}{ML^2T^{-2}} = M^{-1}L^{-2}T^4A^2$$

Q.56. *Calculate the capacity of an isolated charged conducting sphere.* (2)

Ans. Consider a spherical conductor of radius a carrying a charge Q. The potential, V, on its surface, due to this charge is $\frac{1}{4\pi\epsilon_0}\frac{Q}{a}$. Hence,

$$C = \frac{Q}{V} = \frac{Q \times 4\pi\epsilon_0 a}{Q} = 4\pi\epsilon_0 a$$

Thus, the capacity of a spherical conductor, of radius a, equals $4\pi\epsilon_0 a$

Q.57. *What is the approximate value of the capacitance of a spherical conductor having a radius equal to that of the earth ?* (2)

Ans. The radius of the earth is about 6300 km. Hence, the capacitance is nearly

$$C \approx 4\pi\epsilon_0 \times (6300) \times 10^3\ F = \frac{1}{9 \times 10^9} \times 63 \times 10^5\ F = \mathbf{700\ \mu F}$$

Q.58. *What is a capacitor ?* (1).

Ans. The capacitor is a system of two conductors carrying equal and opposite charges, + Q and -Q, and separated by a (small) distance, by an insulator or dielectric.

Q.59. *Briefly explain the principle of a capacitor.* (2)

Ans. Consider the situation where an uncharged plate (plate 2) is brought near another plate (plate 1) on which a charge, say, +Q, has been put. Because of the phenomenon of electrostatic induction, the charged plate would *induce* a charge –Q on the *near* end of the uncharged plate and a charge +Q on its far end. The potential of the original charged plate (plate1) would now be due to

(i) its own charge +Q, (ii) the charge –Q, on the near end, of the (originally uncharged) other plate (plate 2) and (iii) the charge +Q, on the far end, of the (originally uncharged) other plate (plate 2)

Since, the *induced* charge –Q is nearer to the original charged plate 1 (compared to the *induced* charge +Q), the potential, due to –Q, on plate 1 would be a little 'stronger' than that due to (the induced charge) +Q. Also,

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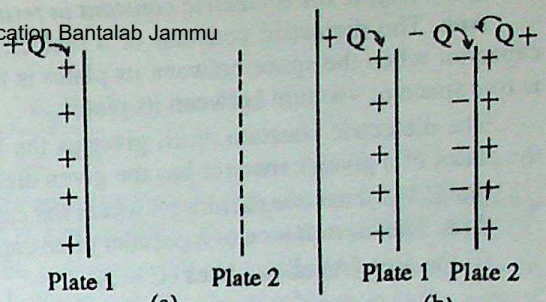
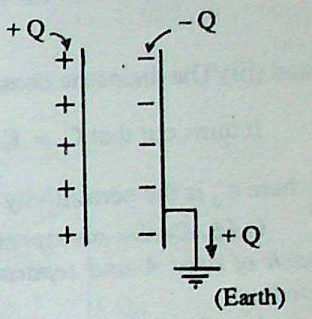
since the induced charge –Q would be producing an effect of the opposite sign to that of the original charge +Q on plate 1, the net effect is a *lowering* of the potential of plate 1. We, thus, observe that :

The mere presence of an uncharged plate near a charged plate tends to lower its potential. Hence the ratio Q/V (charge per unit potential), which measures the capacitance, tends to go up.



Let us next imagine that the plate 2 has been 'earthed'. The induced charge –Q, on its near end, would not be *free* to flow to 'earth' as it is 'held back' by the attractive force of charge +Q on plate 1. However, the induced charge +Q, on its far end, does not experience any such constraint and would, therefore, 'flow down' to 'earth'. The plate 2 now has only the charge –Q on it and this tends to lower the potential of plate 1. Hence, after earthing of plate 2, the potential of plate 1 goes down still more. This means that the capacitance (=Q/V) of this plate goes up considerably.



It then follows that *if we have an 'earthed' plate kept near a charged plate, the capacitance of the latter goes up considerably.* This forms the underlying principle of a capacitor.

Q.60. *Define the SI unit of capacitance.* **(CBSE 1994) (1)**

Ans. The SI unit of capacitance is the *farad.* A conductor, is said to have a capacity of one farad, if on being given a charge of one coulomb, it acquires a potential of one volt.

A capacitor is said to have a capacity of one farad, if charges of (+) one coulomb and (–) one coulomb, on its two plates, produce a potential difference of one volt between them.

Q.61. *Write the physical quantity that has the units coulomb (volt)$^{-1}$. Is it a scalar or a vector quantity?* **(CBSE 1993 Comptt) (1)**

Ans. The physical quantity, that has the units coulomb (volt)$^{-1}$, is capacitance. It is a scalar quantity.

Q.62. *When a dielectric is inserted in between the plates of a capacitor, how does the capacitance change and why ?* **(2)**

Ans. The capacitance goes up by a factor ϵ_r (or k) characteristic of the dielectric. We call ϵ_r (or k) as the *relative permittivity* (or the *dielectric constant*) of the given dielectric.

Q.63. *Explain the principle of a capacitor. Derive an expression for the capacity of a parallel plate capacitor.* **(CBSE 1994) (3)**

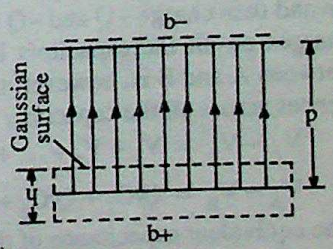
Ans. For the principle of the capacitor, refer to the answer to Q. no. 59 above.

The capacity of a parallel plate capacitor can be derived as follows :

The parallel plate capacitor consists of two parallel conducting plates kept a small distance apart. We first calculate the field in the region between the plates by using Gauss's law. Here we choose a Gaussian surface of height h closed by plane caps of area A that have same shape and size as the plates of the capacitor, we then have

$$\int \mathbf{E} \cdot \mathbf{dS} = q/\epsilon_0$$

i.e., $$EA = q/\epsilon_0$$



This field is uniform in the region between the plates so that the p.d. can be simply written as

$$V = Ed = \frac{qd}{A\epsilon_0}$$

The capacity of a parallel plate capacitor is, therefore.

$$C = \epsilon_0 A/d$$

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Q.64. *Define the dielectric constant in terms of the capacitance of a capacitor.* **(CBSE 1995)** (1)

Ans. The dielectric constant of a dielectric is simply the ratio C′/C, where C′ is the capacity of a given capacitor when the space between its plates is filled with the given dielectric and C is its capacitance when there is free space or vacuum between its plates.

The dielectric constant, thus, gives us the factor by which the capacitance goes up when the space between the plates of a given capacitor has the given dielectric replacing free space (or vacuum).

Q.65. *What are the factors on which the capacitance of a parallel plates capacitor depends ?* (1)

Ans. The capacitance of a parallel plate capacitor depends on

(i) the area (A) of its plates ($C \propto A$)

(ii) the separation (d) between its plates $\left(C \propto \frac{1}{d}\right)$

and (iii) The dielectric constant (K) of the dielectric filling the space between its plates. ($C \propto K$)

It turns out that $C = K \frac{\epsilon_0 A}{d}$

where ϵ_0 is the permittivity of free space or vacuum. ($\epsilon_0 \approx 8.85 \times 10^{-12}\ N^{-1}\ m^{-2}\ C^2$)

Q.66. *Derive an expression for the capacitance of a parallel plate capacitor having two identical plates, each of area A and separated by a distance d, when the space between the plates is filled with a dielectric medium.* **(CBSE 1994)** (3)

Ans. Please see answer to Q. no. 63, 64, 65.

Q.67. *A parallel plate capacitor, when there is vacuum between the plats, has capacitance C. What will be the value of the capacitance when*

(i) the distance between the plates is doubled (ii) a sheet of thickness t of a dielectric or relative permittivity K is introduced between the plates, (Assume t = d). **(CBSE 1993 Comptt.)** (3)

Ans. The capacitance C of a (vacuum) parallel plate capacitor, made up of two plates of area A each separated by a distance d is given by

$$C = \frac{\epsilon_0 A}{d}$$

(i) When the distance between the plates is doubled, the capacitance becomes C′ where

$$C' = \frac{\epsilon_0 A}{2d}$$

Hence, C′ = C/2, i.e., the capacitance becomes half of its previous value.

(ii) We are given that t = d, i.e., the space between the plates is completely filled with a dielectric of dielectric constant K. The capacitance, therefore, goes up by a factor K, i.e., the new capacitance C″ is given by

$$C'' = KC$$

Q.68. *Derive an expression for the equivalent capacitance of two capacitors, C_1 and C_2, connected in series.* **(CBSE 1993)** (2)

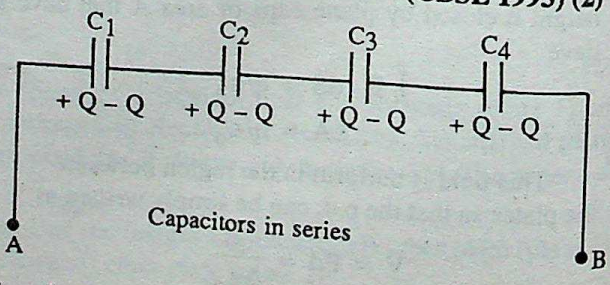
Ans. Let us consider the series combination shown in Fig. below. Here, if all the capacitors are initially without charge and then charge +Q and –Q are applied to A and B, the charges on all the capacitors become the same. The p.d. between A and B is, however, the sum of the potential differences across all the capacitors i.e.,

$$V_A - V_B = V_1 + V_2 + ... + V_n$$

or $V_A - V_B = Q/C_1 + Q/C_2 + Q/C_3 + ... + Q_n/C_n$

The equivalent capacitance of the series connection is given by

$$C_{eq} = Q/(V_A - V_B)$$



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$$\therefore \frac{1}{C_{eq}} = \frac{V_A - V_B}{Q} = \left(\frac{1}{C_1} + \frac{1}{C_2} + \ldots + \frac{1}{C_n}\right)$$

For two capacitors, we would have $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$ or $C = \frac{C_1 C_2}{C_1 + C_2}$

Q.69. *Derive an expression for the total capacitance when three capacitors of capacitance C_1, C_2, and C_3, are connected in parallel. Write two applications of capacitors in electrical circuits.* **(CBSE 1994) (2)**

Ans. The parallel connection is shown in Fig. below Here the p.d. across all the capacitors is the potential difference applied between the terminals A and B. Also, the total charge put into the combination is the sum of the charges on each capacitor, i.e.,

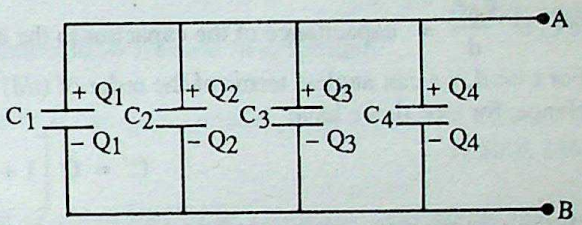
$Q_{Total} = Q_1 + Q_2 + Q_3 + \ldots + Q_n$

But, $Q_i = C_i (V_A - V_{B),}$ $(i = 1, 2, \ldots n)$, by the definition of capacitance.

Hence, $Q_{Total} = (C_1 + C_2 + \ldots + C_{n)}\ (V_A - V_B)$

The equivalent capacitance of a parallel combination of capacitors is, therefore,

$$C_{eq} = \frac{Q_{Total}}{(V_A - V_B)} = C_1 + C_2 + \ldots + C_n$$



For three capacitors, we would then have

$C = C_1 + C_2 + C_3$

The capacitors find, among other, the following uses in practice :

(i) The capacitors are used for 'storing' charges in static machines and rectifiers etc.

(ii) The capacitors are extensively used in electronic circuits. The fact, that they act practically as a 'by pass' for high frequency a.c., finds considerable use in these circuits.

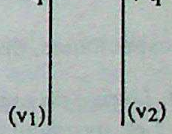
Q.70. *Define capacitance. Two capacitors, of equal capacitance, when connected in series , have a net capacitance of C_1 and, when connected in parallel, have a net capacitance of C_2. What will be the value of C_1 / C_2 ?* **(CBSE 1995, Comptt.) (2)**

Ans. The capacitance of a capacitor is the ratio of the magnitude of charge to be put on either of its two plates to cause a unit potential difference between its two plates. Thus,

$$C = \frac{q}{V_1 - V_2}$$

The unit of capacitance (=coulomb/volt) is the farad (F).

A capacitor has a capacitance of one farad, if charges of ± 1 coulomb on its two plates, establish a p.d. of 1 volt between them.



When the two equal capacitors are connected in series, we have

$$\frac{1}{C_1} = \left(\frac{1}{C} + \frac{1}{C}\right) = \frac{2}{C} \text{ or } C_1 = \frac{C}{2}$$

When the same two equal capacitors are connected in parallel, we have

$C_2 = C + C = 2C$

$$\therefore C_1/C_2 = C/2 \times \frac{1}{2C} = \frac{1}{4}$$

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Q.71. *What is a dielectric ? A dielectric slab of thickness t is kept between the plates of a parallel plate capacitor separated by a distance d. Derive an expression for the capacity of the capacitor for t << d.*

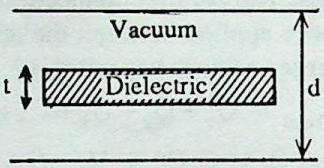
(CBSE 1994) (3)

Ans. A dielectric or an insulator is a material having practically no free charge carriers in it. It, therefore, does not allow electricity to flow (easily) through it.

A dielectric slab of thickness t is equivalent to a thickness t/K of vacuum where K, is the 'dielectric constant' of the dielectric. Hence, the effective separation between the plates of the parallel plate capacitor is

$$d' = (d - t) + t/K = d + t\left(\frac{1}{K} - 1\right) = d - t\,\frac{(K-1)}{K}$$

$$= d\left[1 - \left(\frac{(K-1)}{K}\right)\frac{t}{d}\right]$$



The capacitance of the given capacitor is

$$C' = \frac{\epsilon_0 A}{d'} = \frac{\epsilon_0 A}{d}\left[1 - \left(\frac{K-1}{K}\right)\frac{t}{d}\right]^{-1} = C\left[1 + \left(\frac{K-1}{K}\right)\frac{t}{d} + \frac{(-1)(-2)}{2!}\left\{\frac{(K-1)}{K}\,\frac{t}{d}\right\}^2 + \ldots\right]$$

where $C = \frac{\epsilon_0 A}{d}$ = capacitance of the capacitor in the absence of the dielectric.

For t << d, we can neglect terms of the order of $(t/d)^2$ and higher order terms.

Hence, for t << d, we have

$$C' = C\left[1 + \left(\frac{K-1}{K}\right)\frac{t}{d}\right]$$

Q.72. *A slab of a material of dielectric constant K has the same area as the plates of a parallel plate capacitor, but has a thickness (3/4)d, where d is the separation between the plates. How is the capacitance changed when the slab is inserted between the plates ?* (3)

Ans. We know that in a capacitor of thickness t of a dielectric (of dielectric constant k) is equivalent to a thickness t/k of free space or vacuum. Hence, in the present case, the total equivalent 'vacuum separation' of the plates of the capacitor is

$$d' = \left(d - \frac{3}{4}d\right) + \frac{3/4\,d}{K} = \frac{1}{4}\,d\left[1 + \frac{3}{K}\right] = \frac{d\,(K+3)}{4K}$$

Therefore, the capacitance has the value

$$C' = \frac{\epsilon_0 A}{d'} = \frac{\epsilon_0 A}{d} \cdot \left(\frac{4K}{3+K}\right)$$

The old capacitance value was simply

$$C = \epsilon_0 A/d. \text{ Hence } C' = C \cdot \left(\frac{4K}{3+K}\right)$$

The capacitance, thus, 'goes up' by a factor $\frac{4K}{(3+K)}$

Q.73. *Derive an expression for the energy stored in a capacitor.* **(CBSE 1993, 1995 Comptt.)** (3)

Ans. Let, us calculate the work done in charging up a capacitor of capacity C to charge ±Q on its plates. Let at any stage during the charging process, the charges on the two plates be ±q. The potential difference, V, between the plates of the capacitor at this stage is

$$V' = \frac{q}{C}$$

by definition of the capacitance.

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Let now an additional charge $\pm \delta q$ be put on the plates of the capacitor. Since this charge has to be put at a potential difference V′, the work done δW in this (infinitesimal) step is $\delta W = V' \delta q = \frac{q}{C} \delta q$

The total work done in charging the capacitor is the sum of such infinitesimal step works with q varying from 0 to Q.

We, therefore, integrate above eqn within the limits 0 to Q for q

$$W = \int_0^Q \frac{q}{C} dq = \frac{1}{C} \int_0^Q q\, dq = \frac{1}{C} \left| \frac{q^2}{2} \right|_0^Q = \frac{1}{2} \frac{Q^2}{C}$$

Now, Q = CV. Hence,

$$W = \frac{1}{2} \frac{(CV)^2}{C} = \frac{1}{2} CV^2$$

This work done can be regarded as the stored electrical energy in a capacitor. Hence, the electrical energy stored in a charged capacitor is $\left(\frac{1}{2}\right) CV^2$

Q.74. *Name the physical quantity whose SI unit is (i) coulomb/volt (ii) newton / couloms (iii) joule/coulomb.* **(CBSE 1998) (1)**

Ans. (i) coulomb/volt — Capacitance (ii) newton/coulomb — Electric field strength

(iii) Joule/coulomb — Electric potential.

Q.75. *Derive an expression for the energy stored in a charged parallel plate capacetor with air as the medium between its plates.* **(CBSE 1998) (2)**

Ans. See answers to question 81.

Q.76. *Derive an expression for the energy stored in a parallel plate capacitor with air as the medium between its plates.*

Air is replaced by a dielectric medium of dielectric constant K. How does it change the total energy of the capacitor? **(CBSE 1997) (5)**

Ans. See answer to question 73 for first part. If the air is replaced by a dielectric medium of dielectric constant K, the energy stored becomes $\frac{Q^2}{2KC}$

Q.77. *A capacitor is charged, removed from the charging battery and a dielectric inserted in between the plates. What will happen to the electrostatic potential energy ? Will it increase, decrease or remain the same?* **(2)**

Ans. When the capacitor is charged, there is a certain charge, ±Q, on its two plates. On removing it from the battery, the charge on its two plates continues to be ± Q.

On inserting the dielectric, the capacitance increases by a factor K and becomes KC. Here K is the dielectric constant of the dielectric. The energy stored in the capacitor now becomes $\frac{1}{2} \frac{Q^2}{KC}$ instead of its old value of $\frac{1}{2} \frac{Q^2}{C}$. Hence, the energy stored *decreases* by a factor K, the dielectric constant of the dielectric.

Q.78. *What is the loss in electrical energy when two charged capacitors are connected in parallel?* **(2)**

Ans. Let two charged capacitors, of capacitance C_1 and C_2, charged to potentials V_1 and V_2, be connected in parallel. The equivalent capacitance of the combination is $(C_1 + C_2)$. The total charge on the combination being $(C_1 V_1 + C_2 V_2)$, the potential acquired by the combination would be

$$V = \frac{C_1 V_1 + C_2 V_2}{C_1 + C_2}$$

Hence, the energy stored in the combination is

$$\frac{1}{2} (C_1 + C_2) V^2 = \frac{1}{2} \frac{(C_1 V_1 + C_2 V_2)^2}{(C_1 + C_2)}$$

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The total energy before connecting the two capacitors is $\frac{1}{2}C_1V_1^2 + \frac{1}{2}C_2V_2^2$

Hence, loss in energy $= \frac{1}{2}C_1V_1^2 + \frac{1}{2}C_2V_2^2 - \frac{1}{2}\frac{(C_1V_1 + C_2V_2)^2}{(C_1 + C_2)}$

$$= \frac{1}{2(C_1 + C_2)} \times \begin{bmatrix} C_1^2V_1^2 + C_2^2V_2^2 + C_1C_2V_1^2 + C_1C_2V_2^2 \\ -C_1^2V_1^2 - C_2^2V_2^2 - 2C_1C_2V_1V_2 \end{bmatrix}$$

$$= \frac{C_1C_2}{2(C_1 + C_2)}(V_1 - V_2)^2 = \text{a positive quantity.}$$

Hence, there is always a loss of energy in such a case and the loss is given by the above expression.

Q.79. *Derive the expression for the capacitance of a parallel plate capacitor when the space between the plates is party filled with a dielectric medium of dielectric constant K. Explain, why the capacitance decreases when the dielectric medium is removed between the plates.* **(CBSE 1997) (5)**

Ans. See answer to question no. 71.

Q.80. *Define capacitance of a capacitor. Give its units. Derive an expression for the capacitance of a parallel plate capacitor in which a dielectric medium of dielectric constant K fills the space between the plates.* **(CBSE 1999) (5)**

Ans. The capacitance of a capacitor is the ratio of the magnitude of charge to be put on either of its two plates to cause a unit potential difference between its two plates.

SI units of capacitance is coulomb/volt.

See answer to question no 71 for second part.

Q.81. *Derive an expression for the energy stored in a parallel plate capacitor.*

Assuming that the capacitor is disconnected from the charging battery, explain how the

(i) capacitance (ii) p.d. across the plates (iii) energy stored, in the parallel plate capacitor change when a medium of dielectric consant K is introduced between the plates. **(C.B.S.E. 2000) (5)**

Ans. See answer to question no 73 for first part.

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(i) Capacitance increases from C_0 to $C\ (= KC_0)$

(ii) Potential difference between the plates decreases from V_0 to $V\left(= \frac{V_0}{K}\right)$

(iii) The energy stored decreases from U_0 to $U\left(= \frac{U_0}{K}\right)$

Q.82. *A capacitor is charged to a potential V_1. The power supply is disconnected and the capacitor is connected, in parallel, to another uncharged capacitor.*

(i) Derive an expression for the common potential of the combination.

(ii) Show that the total energy of the combination is less than the sum of the energies stored in them, before they are connected. **(CBSE 1993) (3)**

Ans. Let C_1 be the capacitance of the capacitor charged to a potential V_1. The charges $(= \pm Q_1)$ on its two plates are given by $Q_1 = C_1V_1$.

Let C_2 be the capacitance of the uncharged capacitor. The total capacitance of the combination of the two capacitors, in parallel, is given by $C = C_1 + C_2$.

(i) Since the total charge is only Q_1, the common potential, V, of the combination is given by

$$V = \frac{Q_1}{C} = \frac{C_1V_1}{C_1 + C_2}$$

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(ii) The total energy of the combination is $E_2 = \frac{1}{2}CV^2 = \frac{1}{2}(C_1 + C_2)\frac{C_1^2 V_1^2}{(C_1 + C_2)^2} = \frac{1}{2}\frac{C_1^2 V_1^2}{(C_1 + C_2)}$

Before the two capacitors are connected, the sum of the energies of the two is

$$E_1 = \frac{1}{2}C_1 V_1^{\,2} + \frac{1}{2}C_2 \times 0 = \frac{1}{2}C_1 V_1^{\,2}$$

We have to show that $E_2 < E_1$. To see thus, we notice that

$$E_1 - E_2 = \frac{1}{2}C_1 V_1^{\,2} - \frac{1}{2}\frac{C_1^2 V_1^2}{C_1 + C_2}$$

$$= \frac{1}{2}C_1 V_1^{\,2}\left[1 - \frac{C_1}{C_1 + C_2}\right]$$

$$= \frac{1}{2}C_1 V_1^{\,2}\frac{C_2}{(C_1 + C_2)} = \frac{1}{2}\left(\frac{C_1 C_2}{C_1 + C_2}\right)V_1^{\,2}$$

This is necessarily positive. Hence, $E_1 - E_2 > 0$ or $E_1 > E_2$

This proves the required result.

Q.83. *Define capacitance of a capacitor. Give its S.I. unit. Prove that the total electrostatic energy, stored in a parallel plate capacitor, is* $\left(\frac{1}{2}\right)CV^2$. *Hence derive the expression for the energy density of the capacitor.*

(CBSE 1996) (3)

Ans. For definition of the capacitance, refer to no. 70. For derivation of the expression for the stored energy, refer to no. 73.

We can derive the expression for energy density as follows.

Consider a parallel plate capacitor in which the two plates of area A each are separated by a distance d. The capacity of this capacitor is known to be given by

$$C = \epsilon_0 \frac{A}{d} \qquad ...(i)$$

Let σ be the uniform density of surface charge on either plate. We then have $\sigma = \frac{Q}{A}$

The uniform electric field E at any point in the region between the plates is given by

$$E = \frac{\sigma}{\epsilon_0} \qquad ...(ii)$$

Combining Eqns. (i) and (ii), with the expression, $W = \frac{1}{1}\frac{Q^2}{C}$

we can write the energy stored in a charged capacitor as

$$W = \frac{1}{2}\epsilon_0 E^2 (Ad)$$

Clearly $A \times d$ is the volume of the region between the two plates of the capacitor, the region with which the charged capacitor plates produce an electric field. Thus we can call $\left(\frac{1}{2}\right)\epsilon_0 E^2$ as the energy density of the charged capacitor, the energy per unit volume in the region of its electric field.

Q.84. *Explain the construction and working of a Van-de-Graff generator.* **(3)**

Ans. The Van de-Graff generator is shown schematically in the next figure An insulating column is used to support a hollow spherical conductor. An (charge conveyor) insulated belt passes over a pair of pulleys the lower of which is driven by a belt driving motor. A number of sharp points forming two *metallic combs* are used to serve as a charge spray and a charge collecting metal comb. The lower (charge spraying) comb is held at a positive potential of nearly 50 kV by means of a high voltage d.c. supply unit. The arrangement of the ion

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source, target and high vacuum unit are there to use the high potential attained for accelerating the ions and the making them initiate *nuclear reactions* between the ions and the target.

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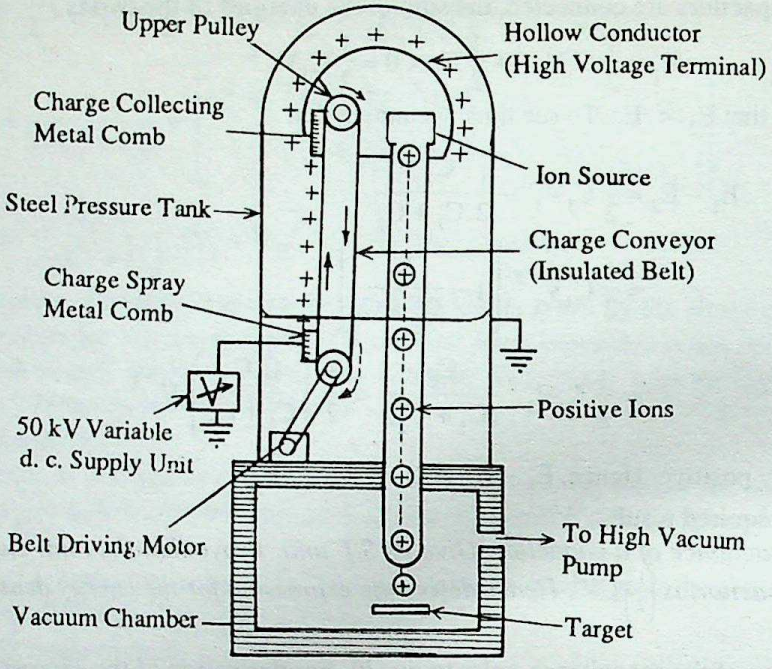

Van de-Graff Generator

The working of the Van de-Graff generator is as follows : Electric charge sprayed (through a process known as *corona breakdown)* on the insulating moving belt resides over its outer surface. As the belt moves, this charge is carried upwards mechanically to within the hollow spherical conductor. There it is collected (again through another corona discharge) by another sharp printed metallic comb which then transfers it to the spherical conductor. This process continues and results in a continual increase in the potential of the hollow spherical conductor.

Q.85. *What puts the limits on the potential that can be reached in a Van-de-Graff generator ?* (2)

Ans. The upper limit of the voltage, which Van de Graff generator can acquire, is limited to that at which the rate of leakage of charge from it through its supports or through the surrounding air equals the rate at which the charge is given to it. The leakage occurs because of the electrical breakdown of the gas (air) present and the limitations of the insulating stand.

Q.86. *What is the order of potentials that can be produced in a Van-de-Graff generator ?* (1)

Ans. A Van-de-Graff generator can be made to attain voltages of the order of 10 million volt which can be kept constant within 1%. It can be used, in practice, to accelerate ions to energies of the order of 6 MeV.

Q.87. *Draw a labelled diagram of a Van-de-Graff generator. Give its principle and explain its working.* **(CBSE 1996)** (3)

Ans. Refer to the answer to Q. no. 84.

Q.88. *Explain the construction, basic principle and working of a Van-de-Graff generator with the help of a diagram.* **(CBSE 1993)** (3)

Ans. Refer to the answer to Q. no. 84.

Q.89. *Why is, in theory, no upper limit on the potentials that can be attained in a Van-de-Graff generator ? Give some applications of this device.* (2)

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SOLVED NUMERICAL PROBLEMS ON UNIT IB

Example 1. *A closed surface of arbitrary shape has a charge of 1 μ C enclosed by it. What is the total electric flux through the surface?*

Solution : We have, by Gauss's theorem, total electric flux through a closed surface

$$= \frac{\text{Charge Enclosed}}{\epsilon_0} = \frac{1 \times 10^{-6}\ \text{C}}{8.85 \times 10^{-12}\ \text{N}^{-1}\text{C}^2\ \text{m}^{-2}} = \mathbf{1.13 \times 10^5\ NC^{-1}\ m^2}$$

Example 2. *A square of side 10 cm is placed inside a uniform electric field. The plane of the square is perpendicular to the direction of the electric field. If the total flux through the square is $10^3\ NC^{-1}\ m^2$, what is the strength of the electric field?*

Solution : We have, by definition, flux of a uniform field = field strength × normal area

$\therefore \quad \phi = EA$

Here $\phi = 10^3\ \text{NC}^{-1}\ \text{m}^2$,

and $A = (10 \times 10^{-2})^2\ \text{m}^2 = 10^{-1}\ \text{m}^2$

$$\therefore \quad E = \frac{10^3\ \text{NC}^{-1}\ \text{m}^2}{10^{-2}\ \text{m}^2} = \mathbf{10^5\ NC^{-1}}$$

Example 3. *A thin plane sheet of area $(2 \times 1)\ m^2$ carries (uniformly) a total charge of 53.10 μ C. What would be the electric field due to this sheet at a point distant 1 cm from the sheet?*

Solution. Since the dimensions of the sheet are large compared to the distance of the field point from it, we can regard the given sheet as an 'infinite' one. The surface charge density of the sheet is

$$\sigma = \frac{53.10 \times 10^{-6}\ \text{C}}{2\ \text{m}^2} = 26.55 \times 10^{-6}\ \text{C–m}^{-2}$$

The electric field E due to an infinite plane sheet is known to be given by $E = \sigma/2\epsilon_0$. Hence,

$$E = \frac{26.55 \times 10^{-6}\ \text{C m}^{-2}}{8.85 \times 10^{-12}\ \text{C}^2\ \text{m}^{-2}\ \text{N}^{-1}} = 3 \times 10^6\ \text{NC}^{-1}$$

The charge on the sheet, being positive, thus electric field would be directed away from the sheet along the normal drawn from the field point on to the sheet.

Example 4. *Calculate the total number of lines of force emanating from a charge of one coulomb.*

Solution : The total number of lines of force equal the *flux* of the electric field (through a closed surface enclosing the charge). The latter quantity equals q/ϵ_0, by Gauss's theorem. Hence, total number of lines of force emanating from a charge of one coulomb = $1/\epsilon_0$.

$$= \left(\frac{1}{8.854 \times 10^{-12}}\right) \text{NC}^{-1}\ \text{m}^2 = \mathbf{1.13 \times 10^{11}\ NC^{-1}\ m^2}$$

Example 5. *The electric potential at a point, distant 0.9 m, from a point charge is + 50 V. Find the magnitude and nature of the charge.* **(CBSE 1995 Comptt.)**

Solution : We know that the potential due to a point charge q, at a point distant r from it, is given by

$$V = \frac{1}{4\pi\epsilon_0}\frac{q}{r}$$

$$\therefore \quad q = 4\pi\epsilon_0 Vr = \frac{1}{9 \times 10^9} \times 50 \times 0.9\ \text{C} = 5 \times 10^{-9}\ \text{C} = \mathbf{5\ nC}$$

Thus, the required charge is a positive charge of **5 nC.**

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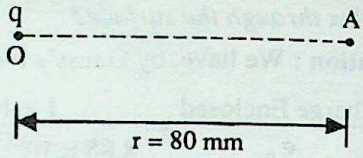
Example 6. *The electric potential is + 80 V at a point distant 80 mm from a point charge. What is magnitude of charge? What is electric field due to this charge at a point distance 20 cm?*

Solution : Let q be point charge at O. A is a point distant r = 80 mm $= 8 \times 10^{-2}$ m from O. The electric potential V at A is $V = 9 \times 10^9 \left(\frac{q}{r}\right)$



Given V = 80 V.

$$\therefore \quad 80 = \frac{9 \times 10^9 \times q}{8 \times 10^{-2}}$$

$$\text{or} \quad q = \frac{64 \times 10^{-1}}{9 \times 10^9} = 7.1 \times 10^{-10} \text{ C} = 0.71 \text{ nC}$$

The electric field E at a point distant $r_1 = 20$ cm $= 20 \times 10^{-2}$ m is

$$E = \frac{9 \times 10^9 \times 7.1 \times 10^{-10}}{(0.2)^2} \text{ NC}^{-1} = 1.597 \times 10^2 \text{ NC}^{-1} \approx \mathbf{1.6 \times 10^2 \text{ NC}^{-1}}$$

Example 7: *(i) Calculate the electric potential at a point x due to a charge of 0.5 μC located at 10 cm from it.*

(ii) Also calculate the work done in bringing a change of 3×10^{-9} C from infinity to the point X.

(CBSE 1997 Compt)

Solution: (i) Here, $q = 0.5\ \mu c = 0.5 \times 10^{-6}$ C, r = 10 cm = 0.1 m

$$V_x = \frac{1}{4\pi\epsilon_0}\frac{q}{r} = 9 \times 10^9 \times \frac{0.5 \times 10^{-6}}{0.1} = \mathbf{4.5 \times 10^4 \text{ V}}$$

(ii) Here, $q_0 = 3 \times 10^{-9}$ C

$$\therefore \ W = q_0 \ (V_x - V_\infty) = 3 \times 10^{-9} (4.5 \times 10^4 - 0) = \mathbf{1.35 \times 10^{-4} \text{ J}}$$

Example 8. *Two point electric charges A and B of 1.5 μC and 2.5 μC respectively are kept 30 cm apart in air. Calculate the electric potential at a point C which is 10 cm from the mid-point of straight line AB and is on a plane normal to AB.*

(CBSE 1998)

Solution: Consider the figure.

$$AC = \sqrt{AD^2 + CD^2} = \sqrt{15^2 + 10^2} = \sqrt{225 + 100} = 18.02 \approx 18 \text{ cm.}$$

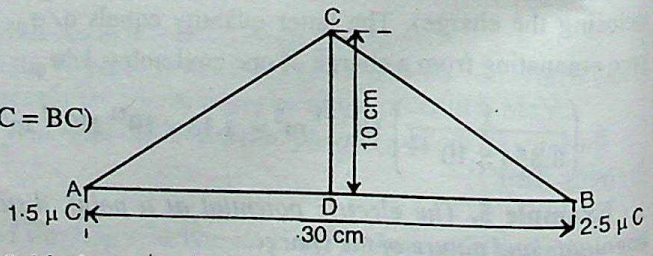
As D is mid-point of AB, therefore, AC = BC = 18 cm.

Now, electric potential at C,

$$V_C = \frac{1}{4\pi\epsilon_0}\left[\frac{1.5 \times 10^{-6}}{AC} + \frac{2.5 \times 10^{-6}}{BC}\right]$$

$$= \frac{1}{4\pi\epsilon_0}\frac{10^{-6}}{AC}[1.5 + 2.5] \qquad (\because \ AC = BC)$$

$$= 9 \times 10^9 \times \frac{10^{-6}}{0.18} \times 4 = \mathbf{2 \times 10^5 \text{ V}}$$



Example 9. *A proton placed in a uniform electric field of magnitude 2000 N/C moves between two points in the direction of electric field. If the distance between the points is 0.2 m find the value of (i) p.d. between the points (ii) work done.*

(CBSE 2000)

Solution: Here, $q = +1.6 \times 10^{-19}$ C, d = 0.2 m, E = 2000 N/C

(i) p.d. $= -E.d = -2000 \times 0.2 = \mathbf{-400 \text{ V}}$

(ii) Work done $= q.V = 1.6 \times 10^{-19} \times 400 = \mathbf{6.4 \times 10^{-17} \text{ J}}$

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Example 10. *Find the electric field between two metal plates 3 mm apart connected to a 12 V battery.* **(CBSE 1993)**

Solution : The difference of potential V between plates is the p.d. of battery i.e.

$V = 12V$. Also distance between plates $= d = 3\ mm = 3 \times 10^{-3}\ m$.

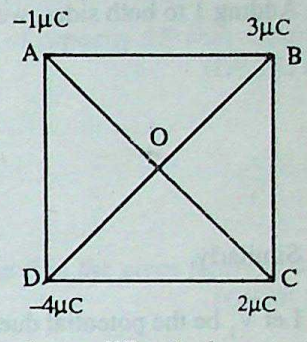
By definition.

$$|\text{Electric field}| = \frac{\text{Difference of potential}}{\text{Distance}} = \frac{V}{d} = \frac{12}{3 \times 10^{-3}} = \mathbf{4 \times 10^3\ V\ m^{-1}}$$

Example 11. *Charges are placed at the corners of a square of side 0.1 m as shown in Fig. below What is work done in moving a charge of 5μC from O to A?*

Solution : Let V_o and V_A be potential at O and A due to charges at the corners of square. Clearly

$$V_o = 9 \times 10^9 \left[\frac{-1}{OA} + \frac{3}{OB} + \frac{2}{OC} + \frac{-4}{OD}\right] \times 10^{-6} = 0$$



and $$V_A = 9 \times 10^{-6} \times 10^9 \left[\frac{3}{AB} + \frac{2}{AC} + \frac{-4}{AD}\right]$$

$$= 9 \times 10^3 \left[\frac{3}{0.1} + \frac{2}{0.1\sqrt{2}} - \frac{4}{0.1}\right] = 3.73 \times 10^3\ V$$

The work done in moving a charge q from O to A is

$$W = q\,[V_A - V_o] = 5 \times 10^{-6} \times 3.73 \times 10^3 = \mathbf{18.65 \times 10^{-3}\ J}$$

Example 12. *Charges each equal to 2μ C is placed at x = 1m, x = 2m, x = 4m, ... What is the potential at the origin of x-axis?*

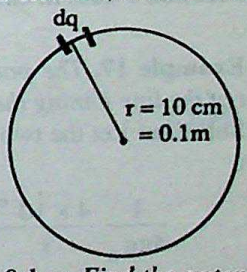
Solution : The total potential V at the origion O is

$$V = \frac{1}{4\pi\epsilon_0}\left[\frac{q}{1} + \frac{q}{2} + \frac{q}{4} .....\right] = \frac{q}{4\pi\epsilon_0}\left[1 + \frac{1}{2} + \frac{1}{4} .... \infty\right]$$

$$= \frac{q}{4\pi\epsilon_0}\left[\frac{1}{1 - \frac{1}{2}}\right] = \frac{2q}{4\pi\epsilon_0} = 2 \times 2 \times 10^{-6} \times 9 \times 10^9\ V = 36 \times 10^3\ V = \mathbf{36\ kV}$$

Example 13. *A metal wire is bent into a circle of radius 10 cm. It is given a charge of 200μC which spreads on it uniformly. Calculate the electric potential at its centre.* **(CBSE 1995 Comptt.)**

Solution : Consider an element of charge dq of the wire. The potential due to this element, at the centre, is



$$dV = \frac{1}{4\pi\epsilon_0}\frac{dq}{r}$$

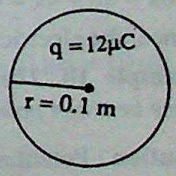
The total potential at the centre is, therefore,

$$V = \sum dV = \sum \frac{1}{4\pi\epsilon_0}\frac{dq}{r} = \frac{1}{4\pi\epsilon_0 r}\sum dq$$

$$= \frac{9 \times 10^9}{0.1} \times 200 \times 10^{-6}\ \text{volt} = 18 \times 10^6\ \text{volt}$$

Example 14. *A charge of 12 μC is given to a hollow metallic sphere of radius 0.1 m. Find the potential at the (i) surface (ii) centre of the sphere.* **(CBSE 1995)**

Solution : For the surface points (as well as for external points), the charged hollow sphere is equivalent to a point charge located at the centre of the sphere.



Hence, potential at the surface is given by

$$V_s = \frac{1}{4\pi\epsilon_0}\frac{q}{r} = 9 \times 10^9 \times \frac{12 \times 10^{-6}}{0.1}\ \text{volt} = 108 \times 10^4\ \text{volt}.$$

The potential at all internal points inside a charged hollow sphere, is the same as that on the surface. Hence, potential at the centre of the sphere is also 1.08 million volt.

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Example 15. *A charge Q is distributed over the concentric hollow spheres of radii r and R (R > r) such th the surface charge densities are equal. Find the potential at the common centre.*

Solution. Let Q_1 and Q_2 be the respective charges distributed over concentric hollow spheres of radii r an R. Then it is obvious that $Q = Q_1 + Q_2$

Since after the distribution of charge Q on the two hollow concentric spheres, their surface charge densiti are equal, we must have

$$\frac{Q_1}{4\pi r^2} = \frac{Q_2}{4\pi R^2} \Rightarrow \frac{Q_1}{Q_2} = \frac{r^2}{R^2}$$

Adding 1 to both sides, we get

$$\frac{Q_1}{Q_2} + 1 = \frac{r^2}{R^2} + 1 \quad \text{or} \quad \frac{Q_1 + Q_2}{Q_2} = \frac{r^2 + R^2}{R^2}$$

$$\frac{Q}{Q_2} = \frac{r^2 + R^2}{R^2} \Rightarrow Q_2 = \frac{R^2}{(r^2 + R^2)} Q$$

Similarly, $$Q_1 = \frac{r^2}{(r^2 + R^2)} Q$$

Let V_1 be the potential due to Q_1 and V_2 be the potential due to Q_2. We then have

$$V_1 = \frac{r^2}{(r^2 + R^2)} \frac{Q}{4\pi\epsilon_0 r}$$

and $$V_2 = \frac{R^2}{(r^2 + R^2)} \frac{Q}{4\pi\epsilon_0 R}$$

The required potential V is then given by

$$V = V_1 + V_2 = \frac{Q}{4\pi\epsilon_0} \left(\frac{R + r}{R^2 + r^2} \right)$$

Example 16. *Obtain the energy in joules, acquired by an electron beam, when accelerated through potential difference of 2000 volt.* **(CBSE, 199**

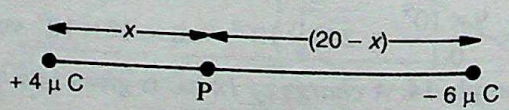
Solution : Gain in energy = charge × accelerating potential

$$= 1.6 \times 10^{-19} \times 2000 \text{ J} = \mathbf{3.2 \times 10^{-16} J}$$

Example 17. *The point charges +4 μC and – 6μC are separated by a distance of 20 cm in air. At wha point of the line joining the two charges is the electric potential zero?* **(CBSE 1997 Compt**

Solution: Let the two point charges be placed as shown in the figure. Let at P the electric potential be zero Then,

$$\frac{1}{4\pi\epsilon_0} \frac{4 \times 10^{-6}}{x} + \frac{1}{4\pi\epsilon_0} \frac{-6 \times 10^{-6}}{(20 - x)} = 0$$



$$\Rightarrow \quad \frac{4}{x} = \frac{6}{(20 - x)}$$

$$\Rightarrow 6x - 80 + 4x = 0 \Rightarrow 10x = 80 \Rightarrow x = 8$$

Hence, the electric potential at a distance of 8 cm from the point charge 4 μC is zero.

Example 18. *The work done in moving a charge of 3C between two points is 6J. What is potentia difference between points?* **(CBSE 1993**

Solution : Potential difference = $\frac{\text{work done}}{\text{charge}} = \frac{6\text{J}}{3\text{C}} = 2\text{ J C}^{-1} = \mathbf{2V}$

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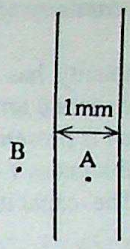
Example 19. *In a parallel plate capacitor a p.d. of 100 V is maintained between the plates. What will be the electric field at points A and B?* **(CBSE 1995 Comptt.)**

Solution : We have,

field at A

$$\text{Electric field} = \frac{V}{d} = \frac{100\ V}{1 \times 10^{-3}\ m}$$

$$= 10^5\ Vm^{-1}$$



Now point B is outside the two plates.

Hence field at B = zero.

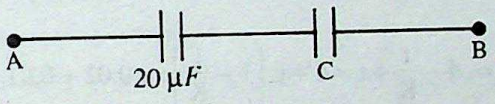
Example 20. *What is the area of the plates of a parallel plate capacitor of capacity 2F with separation between the plates 0.5 cm?* **(CBSE, 1990)**

Solution : The capacity C of a parallel plate capacitor is $C = A\epsilon_0/d$

Given $C = 2\ F$; $d = 0.5\ cm = 5 \times 10^{-3}\ m$, $A = ?$

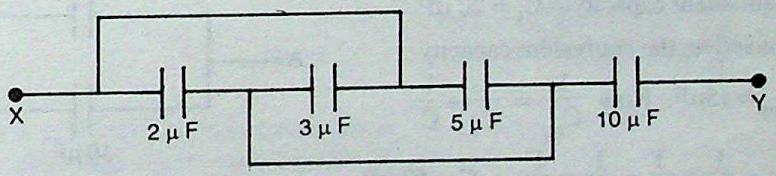
Therefore $A = Cd/\epsilon_0 \quad \frac{2 \times 5 \times 10^{-3}}{8.85 \times 10^{-12}}\ m^2 = \mathbf{1.129 \times 10^9\ m^2}$

Example 21. *The equivalent capacitance of the combination between A and B in the given figure is 15 μF. Calculate the capacitance of the capacitors C.* **(CBSE 1998)**



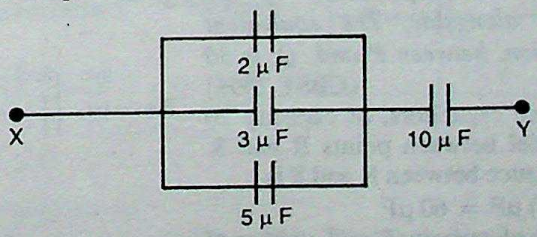
Solution: Since, the two capacitors are in series therefore, the equivalent capacitance between A and B is given by $\frac{1}{C_s} = \frac{1}{C} + \frac{1}{20} \Rightarrow \frac{1}{C} = \frac{1}{C_s} - \frac{1}{20} \Rightarrow \frac{1}{C} = \frac{1}{15} - \frac{1}{20} \Rightarrow C = \mathbf{60\mu F}$

Example 22. *Four capacitors are connected as shown in the figure given below.*



Calculate the equivalent capacitance betwen X and Y. **(CBSE 2000)**

Solution: The given network is equivalent to the following circuit.



2μF, 3μF and 5μF capacitors are in parallel. Their equivalent capacitance = (2 + 3 + 5) μF = 10 μF.

Now, we get a series combination of two 10μF capacitors.

∴ Equivalent capacitance between X and Y = $\frac{10 \times 10}{10 + 10}\ \mu F = \mathbf{5\mu\ F}$

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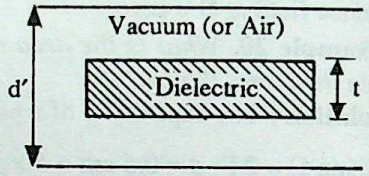
Example 23. *Two plates of a parallel plate capacitor are 0.02m apart. A slab of dielectric constant 5 an thickness 0.01m is introduced between the plates with its faces parallel to them and the distance between th plates is so changed that the capacity of the capacitor remains unchanged. What is the new distance between th plates?*

Solution : Since the capacity has to remain unchanged, the dielectric may not completely fill the spac between the two plates in the second arrangement. The situation is as shown in Fig. below where a parallel sid slab of dielectric of thickness t is present between prallel plates having a separation d′.

It is easily seen that a thickness t of a dielectric in a parallel plate capacitor is equal to a 'slab' of air (vacuum of thickness t/K. The capacitance of the given capacitor in the second arrnagement is, therefo

$$C' = \frac{\epsilon_0 A}{\left[(d' - t) + \frac{t}{K}\right]}$$



In the first case, when there is no dielectric and the separation of the plate is d, the capacitance is $C = \epsilon_0 \frac{A}{d}$

Here, $C' = C$; $d = 0.02$ m; $t = 0.01$ m and $K = 5$

$$\therefore \frac{\epsilon_0 A}{\left[(d' - t) + \frac{t}{K}\right]} = \frac{\epsilon_0 A}{d} \Rightarrow (d' - t) + \frac{t}{K} = d$$

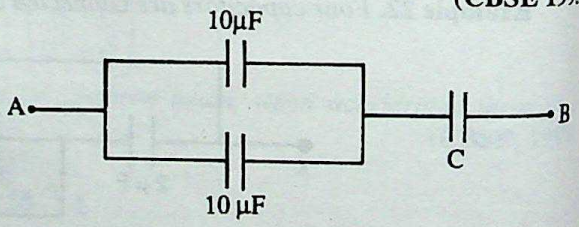
$$d' = d - \frac{t}{K} + t = d + t\left(1 - \frac{1}{K}\right) = 0.02 + 0.01\left(1 - \frac{1}{5}\right)\text{m}$$

$$= 0.02 + 0.008\text{m} = \mathbf{0.028\ m}$$

Thus, the new distance between the plates is 0.028 m

Example 24. *Calculate the capacitance of capacitor C if the equivalent capacitance of combinatio between A and B is 15μF.* **(CBSE 199**

Solution : The capacitors of 10μF are connected in parallel. Their equivalent capacity = $C_1 = 20$ μF.

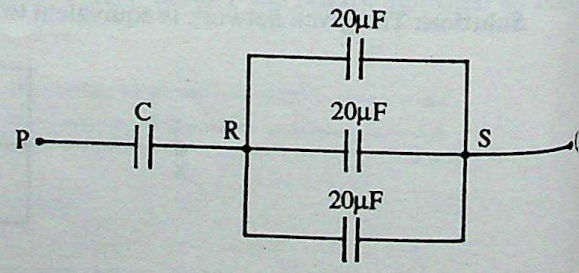


C_1 and C are in series; the equivalent capacity

$$= C_{eq} = 15\mu\text{F}. \text{ Now } \frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C}$$

or $$\frac{1}{C} = \frac{1}{C_{eq}} - \frac{1}{C_1} = \frac{1}{15} - \frac{1}{20} = \frac{1}{60} \quad \therefore \mathbf{C = 60\ \mu F}$$

Example 25. *Calculate the capacitance of the capacitor C in the figure alongside. The equivalent capacitance of the combination, between P and Q, is 30 μF* **(CBSE 1995)**



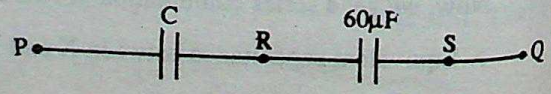
Solution : We have three capacitors, of capacity 20 μF each, connected in parallel between points R and S. Hence, the equivalent capacitance between R and S is

$$(20 + 20 + 20)\ \mu\text{F} = 60\ \mu\text{F}$$

We now have a capacitor of capacity C and another of capacity 60μF, connected in series. These give us an equivalent capacitance of 30μF between P and Q. Hence,

$$\frac{1}{30} = \frac{1}{C} + \frac{1}{60} \text{ or } \frac{1}{C} = \frac{1}{30} - \frac{1}{60} = \frac{1}{60}$$

$$\therefore \quad \mathbf{C = 60\ \mu F}$$



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Example 26. *Two capacitors of equal capacitance, when connected in series, have a net capacitance C_1 and when connected in parallel, have a net capacitance C_2. What is value of C_1/C_2?* **(CBSE 1993 Comptt.)**

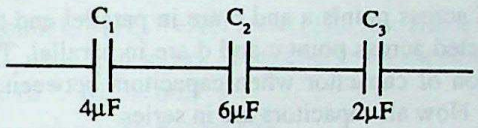
Solution : Let C be capacity of each capacitor. When capacitors are connected in series.

$$\frac{1}{C_1} = \frac{1}{C} + \frac{1}{C} \quad \text{or} \quad C_1 = \frac{C}{2}$$

When capacitors are connected in parallel

$$C_2 = C + C = 2C \quad \therefore \quad \frac{C_1}{C_2} = \frac{(C/2)}{2C} = \frac{1}{4}$$

Example 27. *Three capacitors are connected to one another, as shown in Fig. below. The potential difference across C_2 is 50V. What is the potential difference across C_1 and C_3?*



Solution. The three capacitors are connected in series. Charge on each capacitor is same.

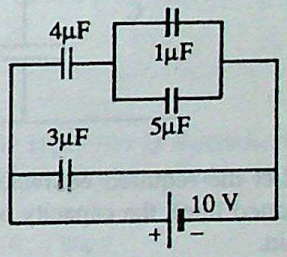
The charge on capacitor C_2 is $q = C_2V_2 = 6 \times 10^{-6} \times 50 = 3 \times 10^{-4}$ C

Charge on capacitor C_1 and C_3 is also 3×10^{-4} C. Therefore, V_1 = poential difference across C_1

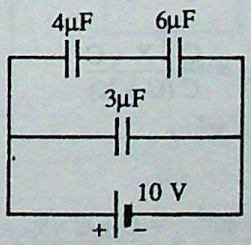
$= 3 \times 10^{-4}/4 \times 10^{-6} = 0.75 \times 10^2$ V = **75 V**

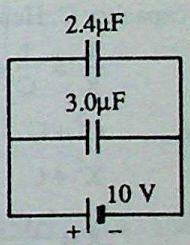
V_2 = potential difference across $C_s = 3 \times 10^{-4}/2 \times 10^{-6} = 1.5 \times 10^2$ V = **150 V**

Example 28. *Find the equivalent capacitance of the combination shown in Fig below. Also find the charge on the 4 μF capacitor.*



Solution : Here 1 μ F and 5 μF capacitors are in parallel. Therefore, their equivalent capacitance is (1 +5) μF = 6μF. The given circuit then can be reduced to as shown.





Now, the 4 μF and 6 μF capacitors are in series. Therefore, their equivalent capacitance C′ is obtained by the relation.

$$\frac{1}{C'} = \frac{1}{4} + \frac{1}{6} = \frac{6+4}{24} = \frac{10}{24}$$

$$\therefore \quad C' = \frac{24}{10} = 2.4 \ \mu F$$

The circuit is now reduced to as shown.

Now, the 2.4 μF and 3.0 μF capacitors are in parallel. Therefore, the capacitance of the combination shown is (2.4 + 3.0) μF = 5.4 μF.

It is easy to see that the charge on the 4 μF is the same as on the 2.4 μF capacitor. The voltage across the 2.4 μF capacitor is 10 V and, equivalent charge on the 4 μF capacitor is $2.4 \times 10 =$ **24 μ *C***.

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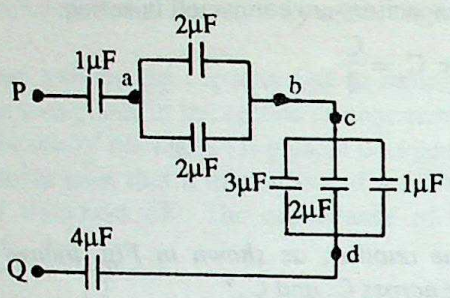
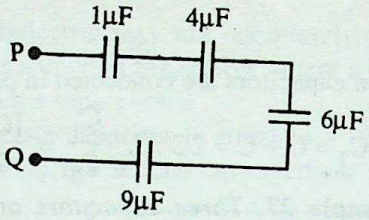
Example 29. *What is the equivalent capacity of the arrangement shown in Fig. below between points P and Q?*



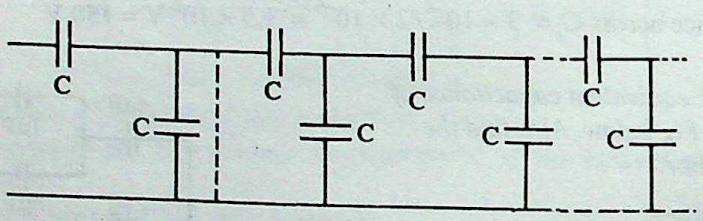


Solution : Capacitors connected across points a and b are in parallel and their equivalent capacity is 4 μF. Similarly, the three capacitors connected across point c and d are in parallel. Their equivalent capacity is 6 μF. Adgacent figure shows the connection of capacitor when capacitors between (i) a and b and (ii) c and d are replaced by their equivalent capacity. Now all capacitors are in series.

Therefore, $\frac{1}{C_{eq}} = \frac{1}{1}+\frac{1}{4}+\frac{1}{6}+\frac{1}{9} = \frac{36+9+6+4}{36} = \frac{55}{36}$

Therefore, $C_{eq} = 36/55\ \mu F = \mathbf{0.6545\ \mu F}$

Example 30. *Find the equivalent capacitance of an infinite chain formed by the repetition of the same link consisting of two identical capacitors, each of capacitance C.*

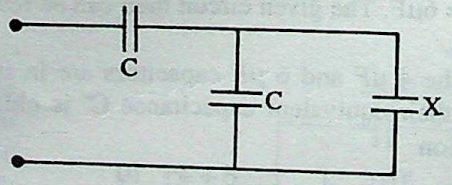


Solution : Let the required equivalent capacitance be X. We can then say that if delete the first 'link' (shown by the dotted line), the capacity of the remaining chain would still be X. This is because of the *infinite* nature of the chain.

The equivalent capacitance of the resulting combination can easily be calculated.

We have C and X in parallel, giving rise to an equivalent capacitance (C + X) which is connected in series to the capacitor C. Hence,

$$\frac{1}{X} = \frac{1}{C}+\frac{1}{C+X} = \frac{C+X+C}{C(C+X)}$$

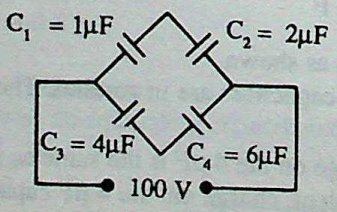


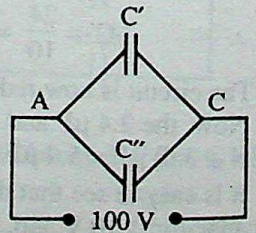
or $C^2 + C$ $\quad + X^2$

$\therefore$ $X^2 + C$

$\therefore$ $X = \frac{-C \pm \sqrt{C^2+4C^2}}{2} = \frac{-C+C\sqrt{5}}{2} = \frac{(\sqrt{5}-1)}{2}\ C = \mathbf{0.62\ C}$

Example 31. *In the arrangement shown in figure alongside what is (i) the equivalent capacity : (ii) p.d. across each capacitor and (iii) charge on each capacitor?*





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Solution : Capacitor C_1 and C_2 are in series. Their equivalent capacity C′ is

$$\frac{1}{C'} = \frac{1}{1}+\frac{1}{2}=\frac{3}{2} \quad \text{or} \quad C' = (2/3)\,\mu F \qquad ...(i)$$

Similarly, C_3 and C_4 are in series. Their equivalent capacitor C″ is

$$\frac{1}{C''} = \frac{1}{4}+\frac{1}{6}=\frac{5}{12} \quad \text{or} \quad C'' = \frac{12}{5}\,\mu F \qquad ...(ii)$$

Capacitors C′ and C″ are connected in parallel. The equivalent capacity

$$C_{eq} = C' + C'' = (2/3) + (12/5) = (46/15)\,\mu F \qquad ...(iii)$$

The charge Q′ on capacitor C′ is

$$Q' = C'V + (2/3) \times 100 \times 10^{-6}\,C = 0.667 \times 10^{-4}\,C$$

Similarly, charge Q″ on capacitor C″ is $Q'' = C''V = (12/5) \times 100 \times 10^{-6} = 2.4 \times 10^{-4}\,C$

Now C′ is the equivalent of C_1 and C_2 in series. Since charge on capacitor in series is same

V_1 = p.d across $C_1 = 0.667 \times 10^{-4}/10^{-6} = 66.7$ V

V_2 = p.d across $C_2 = 0.667 \times 10^{-4}/2 \times 10^{-6} = 33.3$ V

Similarly V_3 = p.d. across C_3

$= 2.4 \times 10^{-4}/4 \times 10^{-6} = 0.6 \times 10^2 = 60$ V

V_4 = p.d across $C_4 = 2.4 \times 10^{-4}/6 \times 10^{-6} = 40$ V

Example 32. *How much energy will be stored by a capacitor of 470 μF when charged by a batterty of 20 V?* **(C.B.S.E. 1994)**

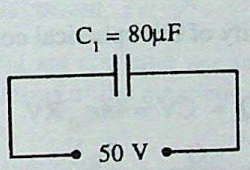
Solution : The energy, E, stored in a capacitor of capacity C, charged to a p.d. V is $E = \frac{1}{2}CV^2$

Given $C = 470\,\mu F = 470 \times 10^{-6}$ F, $V = 20$ V

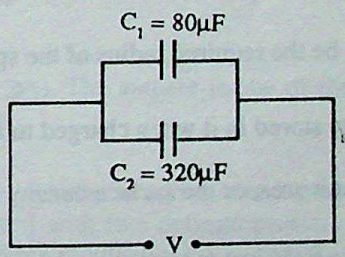
$\therefore\ E = \frac{1}{2} \times 47 \times 10^{-5} \times (20)^2$ J $= 94 \times 10^{-3}$ J $=$ **94 mJ**

Example 33. *A 80 μF capacitor is charged by 950 V battery. The capacitor is disconnected from battery and then connected across another uncharged 320 μF capacitor. Calculate the charge on second capactor.* **(CBSE 1994)**

Solution :



(a)



(b)

Fig. above (a) above shows capacitor $C_1 = 80\,\mu F$ connected to a p.d.; $V_1 = 50$ V. The charge Q on capacitor.

$$Q = C_1V_1 = 80 \times 10^{-6} \times 50\,C = 4 \times 10^{-3}\,C$$

Fig. (b) shows uncharged capacitor $C_2 = 320\,\mu F$ connected across C_1. Let V be the common equilibrium potential. Sum total of charge on C_1 and C_2 equals Q. Therefore,

$$4 \times 10^{-3} = (80 + 320) \times 10^{-6}\,V$$

$$\text{or} \quad V = \frac{4 \times 10^{-3}}{4 \times 10^{-4}} = 10\ V$$

The charge Q_2 on capacitor C_2 in Fig. (b) is

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$Q_2 = C_2V = 320 \times 10^{-6} \times 10 = 3.2 \times 10^{-3}$ C

Example 34. *A capacitor $C_1 = 2\ \mu F$ is charged to a potential of 200 V. Another capacitor $C_2 = 4\ \mu F$ is charged to a potential of 400 V. What is charge and energy stored in each capacitor? The two charged capacitor are joined in parallel. What is their common potential difference? What is the final energy stored in the system? Is there a loss of energy? If yes, what happens to the energy lost?*

Solution :

Q_1 = charge on capacitor $C_1 = 2 \times 10^{-6} \times 200 = 4 \times 10^{-4}$ C

Q_2 = charge on capacitor $C_2 = 4 \times 10^{-6} \times 400 = 16 \times 10^{-4}$ C

Q = Total charge on both capacitors $= Q_1 + Q_2 = 20 \times 10^{-4}$ C

E_1 = Energy stored in capacitor $C_1 = (1/2)\ C_1\ V_1^2 = (1/2) \times 2 \times 10^{-6} \times (200)^2 = 4 \times 10^{-2}$ J

E_1 = Energy stored in capacitor $C_2 = (1/2)\ C_2\ V_2^2 = (1/2) \times 4 \times 10^{-6} \times (400)^2 = 32 \times 10^{-2}$ J

E_i = The total initial energy stored in both capacitors $= E_1 + E_2 = 36 \times 10^{-2}$ J

When the two capacitors are connected in parallel, let V be their common potential. The total charge on both capacitors is $(C_1 + C_2)$ V. Since charge is conserved.

$(C_1 + C_2)\ V = 20 \times 10^{-4}$ or $V = 20 \times 10^{-4}/6 \times 10^{-6} = 3.33 \times 10^2$ V

The total final energy E_f stored in capacitors in parallel is $E_f = (1/2)\ (C_1 + C_2)\ V^2$

$= (1/2) \times 6 \times 10^{-6} \times (333)^2$ J $= 33.2 \times 10^{-2}$ J

The total final energy is less than the total initial energy. Therefore,

Loss of energy $= E_i - E_f = (36 - 33.2) \times 10^{-2}$ J $= \mathbf{2.8 \times 10^{-2}\ J}$

The energy lost appears in the form of heat produced in the wires used to connect the two capacitors in parallel. There is a flow of charge between the two capacitors.

Example 35. *A spark passes in air when the potential gradient at the surface of a charged conductor is 3×10^6 V/m. What must be the radius of an insulated metal sphere which can be charged to a potential of 3 million volt before sparking into the surrounding air? What will be the energy stored immediately before sparking occurs?*

Solution : Let R be the required radius of the sphere. The capacity of this spherical conductor is

$$C = 4\pi\epsilon_0 R$$

Hence, the charge stored in it when charged to a potential V is $Q = CV = 4\pi\epsilon_0 RV$

The charge per unit area, or the surface density of charge is $\sigma = \dfrac{Q}{4\pi R^2} = \dfrac{\epsilon_0 V}{R}$

Hence the electric field just outside the sphere is $E = \dfrac{\sigma}{\epsilon_0} = \dfrac{V}{R}$

Here, $E = 3 \times 10^6$ volt/m, $V = 3 \times 10^6$ volt

Hence, $3 \times 10^6 \dfrac{\text{volt}}{\text{metre}} = \dfrac{3 \times 10^6 \text{ volt}}{R} \Rightarrow R = 1$ m

Hence the required radius is **1 m.**

The energy stored immediately before sparking is, $E = \dfrac{1}{2} CV^2 = \dfrac{1}{2} \times 4\pi\epsilon_0 RV^2$

$= \dfrac{1}{2} \times 4\pi \times 8.85 \times 10^{-12} \times 1 \times (3 \times 10^6)^2$

$\approx$ **500 J**

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UNIT – II

CURRENT ELECTRICITY

CBSE SYLLABUS CONTENTS

Electric current, Ohm's law, resistivity, resistance of different materials, temperature dependence of resistance, colour code of resistors, resistances in series and parallel, Kirchoff's laws-illustration by simple applications. Wheatstone's bridge and its application in metre bridge, principle of potentiometer–its application for comparing e.m.f of two cells and determination of internal resistance of a cell.

Marks allotted : 7 *out of a total of* 70

Periods allotted : 17 *out of a total of* 168.

BASIC FACTS AND FORMULAE

Charges in Motion; Electric Current

The ''motion'' or dynamics of charges gives rise to many new effects which are not associated with these charges when they are at ''rest''.

The flow of charges is said to constitute an electric current; an electric current exists only as long as an actual flow of charges is taking place.

We can maintain a current flow in a circuit by using an 'electric pump' (a battery, etc.) that continuously pumps back the 'flowed out' electrons back to the body originally having an excess of electrons.

Quantitative Definition of Current; Unit of Current

We define current quantitatively as the rate of flow of charge :

$$i = q/t \text{ : for steady flow.}$$

Also, instantaneous current, $i = \frac{dq}{dt}$

The units of current are coulomb per second or ampere (A). The ampere is one of the six fundamental SI units and is defined in terms of the magnetic effects of current.

The Emf

The *emf* between two points is usually defined as the work done in taking a unit positive charge from the second to the first point. It is a potential difference associated with two definite points, characteristics of the source, under suitably defined conditions. The emf is not a force at all; it is the energy (or work done) per unit positive charge.

Charge Carriers; Formula for Current

For most substances, current is due to the flow of electrons. In ionised gases, electrolytic liquids and ionic crystals, both positive and negative ions carry the current.

The current i flowing in a wire of cross section A having n charges (each of charge e) per unit volume is given by $i = n e v A$, where v is the average drift velocity of the moving charges.

Ohm's Experiments; Ohm's Law

The German physicist, Georg Simon Ohm, did a number of experiments in 1826, which led him to the result3: Potential difference/Current = Constant

or $V / I = R$

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The ratio R is known as the electrical resistance $R = V/I$.

The unit of electrical resistance is ohm (Ω) : Ohm = Volt /Ampere

The empirical relation, $\frac{V}{I} = R$ or $V = IR$

is known as *Ohm's law*. We may state this law in words as follows :

The current flowing through a conductor, under constant physical conditions, is proportional to the potential difference across its end.

The words *'constant physical conditions'* in the statement of Ohm's law are important. It turns that the electrical resistance of a given material often changes with changes in its physical conditions like temperature, straight or bent wire, presence or absence of tension, presence or absence of magnetic field in the vicinity, etc. We must not, therefore, change these physical conditions when we are investigating, the effect of potential difference applied on the 'current flowing' in a conductor.

The Ohm (Ω)

The resistance of a substance is one ohm, if the application of a potential difference of 1 volt across its ends causes a current of 1 ampere to flow through it.

The dimensions of resistance (R) are

$$[R] = \frac{\text{Potential Difference}}{\text{Current}} = \frac{\text{Work/Charge}}{\text{Current}} = \frac{ML^2T^{-2}/(AT)}{A} = ML^2T^{-3}A^{-2}$$

Non-Ohmic Resistances

Ohm's law is not valid for all types of materials. Materials that do not obey Ohm's law are known as non-ohmic. We have several non-ohmic 'resistances': e.g., gas discharge tube, thermionic valves, semi-conductor diodes, thermistors, etc.

Factors Affecting the Resistance of a Wire; Electrical Resistivity

The resistance of a wire depends on the nature of its material and its shape and size. Simple considerations show that the resistances (i) of wires of a given diameter increase in *direct* proportion to their lengths and (ii) of wires of a given length increase in *inverse* proportion to their areas of cross section. We may, thus, write.

$$R \propto l, \text{ and } R \propto \frac{1}{A}$$

Here, R is the resistance of a wire of length l and area of cross section A. We may, therefore, write

$$R = \rho \frac{l}{A}$$

where ρ is a constant characteristic of the material and is known as its *electrical resistivity*. It is a constant for a given material at a given temperature equals the resistance of a wire of the given material of length 1 m and area of cross section 1 m^2. The units of ρ are clearly $\left(\because \rho = R \times \frac{A}{l} = \Omega \times \frac{m^2}{m} = \Omega - m\right)$ ohm-metre.

The Physical Cause of Resistance

The electrons moving in a conductor acquire a constant drift velocity in a constant electric field in spite of there receiving an acceleration due to the force exerted on them by the applied field. This is because of their frequent random collisions with the atoms and ions. These collisions 'make them forget', so to say, the effect produced on them by the field and revert them back to the 'zero-field conditions'.

The resistivity ρ of a material is related to the number n of free electrons per unit volume and the relaxation time (the average time between two consecutive collisions) τ by the relation :

$$\rho = \frac{2m}{n e^2 \tau}$$

where m and e are the mass and charge of the electron respectively.

Effect of Temperature on Resistivity

As temperature causes τ to decrease, there is an increase in resistivity with temperature for substances obeying Ohm's law.

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We can define a linear temperature coefficient α of resistance for substances for which the variation of resistance with temperature obeys a linear law :

$$\alpha = \frac{(\rho_t - \rho_0)}{\rho_0 t}$$

For insulators and semiconductors, the resistivity exhibits an exponential decrease with temperature :

$$\rho(T) = \rho_0(T)(E_g/kT)$$

E_g is known as the 'gap energy'. It is ≤ 1 eV for semiconductors and ≥ 1 eV for insulators.

Super Conductors

When a substance lets current flow through it without any opposition, it is referred to as being in the superconducting state or as a superconductor. Metals exhibit this behaviour at low temperatures (~4K). Work is now going on for developing high temperature superconductors.

Colour Code of Resistors

The colour code for resistors works as follows :

1. We associate a colour with each digit : 0, 1, 2, ...9. These colours are as listed below :

Colour	Black	Brown	Red	Orange	Yellow
Associated Digit →	0	1	2	3	4

Colour	Green	Blue	Violet	Grey	White
Associated Digit →	5	6	7	8	9

2. There are three coloured bands on each resistance to indicate its value. The first two bands from one end indicate their corresponding digits, while the third band's colour gives the power of ten with which the number (obtained from the first two coloured bands) must be multiplied to get the resistance value in ohm. Thus, if the colours of the three bands are Yellow, Orange and Blue, the resistance value is

Orange	Yellow	Blue
↓	↓	↓
3	4 ×	10^6 = 34 mega-ohm

3. In addition to the above colours, two additional colours-*silver* and *gold* are also used. They are used for two purposes :

(*i*) If used as the fourth 'colour band', they indicate the *tolerance* or *percentage reliability* in the resistance value obtained from the first three colour bands. A 'silver band' implies a tolerance of 10 % while a 'gold band' implies a tolerance of 5 %.

(*ii*) If used as third colour band, they indicate a *multiplier value* of 10^{-1} for the gold band and 10^{-2} for the silver band.

4. In some resistances, only the three coloured bands are present and there is no gold or silver band. Such resistances have a tolerance of 20 %.

5. There is now another system in use. In this system, the *body colour* of the resistor, the colour at its *(two) ends* and the colour of a *dot* put near the centre of the body are used to indicate the value of the resistor. Here

(i) the *body colour* gives the first significant digit,

(ii) the *end* (common at the two ends) colour gives the second significant digit and

(iii) the *dot* colour gives the power of ten with which the number (obtained from the body colour and the ends colour) must be multiplied to get the resistance value in ohm.

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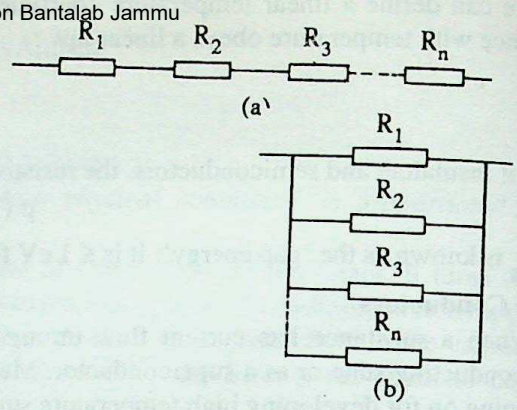
Resistances in Series and Parallel

When resistances $R_1, R_2, ..., R_n$ are connected in series, their equivalent resistance R_s is given by

$$R_S = R_1 + R_2 + \dots R_n \quad \text{or} \quad R = \sum R_i$$



When resistances $R_1, R_2, \dots R_n$ are connected in parallel, their equivalent resistance R_p is given by

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \dots \frac{1}{R_n} \quad \text{or} \quad \frac{1}{R_\rho} = \sum \frac{1}{R_i}$$

Kirchoff's Laws

Kirchoff's two laws help us to analyse electrical circuits in a simple systematic way :

First Law. The algebraic sum of all the currents flowing towards a junction point is zero :

$$\therefore \quad \sum_{j=1}^{n} I_j = 0.$$

Second Law. The algebraic sum of the emf's in any loop of a given circuit is equal to the algebraic sum of the IR products in it :

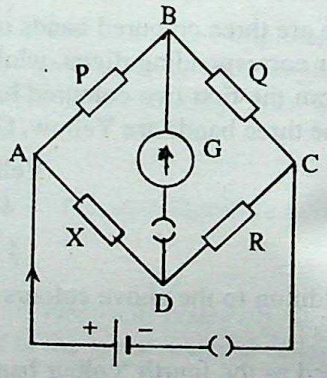
$$\sum E_j = \sum I_j R_j$$

In applying this law, we consider an *emf* as positive if, by itself, it would produce a positive current in the sense of traversal of the loop. Similarly, an IR term is positive, if the current through the resistor considered is in the direction of traversal.

The Wheatstone Bridge

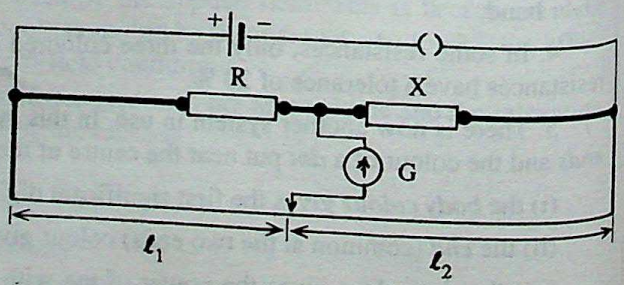
The Wheatstone Bridge is the basis of most of the methods used for resistance measurements. For *balance*, its four arms should have resistances that form a proportion. Thus, at balance,

We have $\frac{P}{Q} = \frac{X}{R}$ or $\frac{P}{X} = \frac{Q}{R}$



The Meter Bridge

The 'post office box' and the 'metre bridge' are two of the practically used forms of the 'Wheatstone Bridge'. Of these, the meter bridge is more easy and convenient to use. Its 'form' and circuit are as shown. At balance, we have



$$\frac{R}{X} = \frac{l_1}{l_2} = \frac{l_1}{100 - l_1} \Rightarrow X = \left(\frac{100 - l_1}{l_1}\right) R$$

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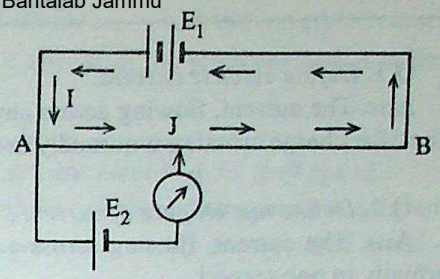
The Potentiometer

A potentiometer is a very useful instrument used to measure an unknown e.m.f. or potential difference. This is achieved by balancing the unknown emf across a known potential difference produced by the flow of current in a network of known characteristics.



The least value of the p.d., that can be measured by using a given potentiometer set up, is known as the *least count* or the *potential gradient* of the given set up.

Two Important Precautions in the Use of a Potentiometer

A potentiometer circuit will not work, unless the following two important 'precautions' are observed :

(1) The 'positive' (or higher p.d.) terminal of both the potentiometer batteries, as well as the unknown emf source, must be connected to the same point (point A) of the potentiometer wire.

(2) The emf (E_1) of the main potentiometer battery must be always greater than the unknown emf (E_2), to be measured.

Comparison of Emf's Using a Potentiometer

The required circuit is as shown. To compare the emf's first the two way key K is thrown into position 1 so that cell E_1 is brought into circuit. The emf of E_1 is balanced across a length l_1 of potentiometer wire by moving jockey J along the potentiometer wire. Then,

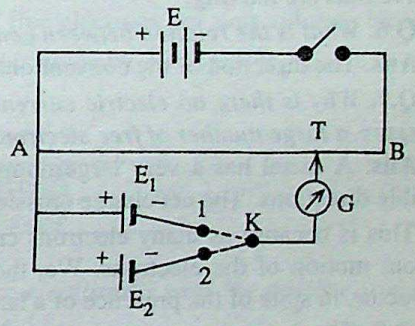
$$E_1 \propto l_1$$

Now the key K is thrown into position 2, so that cell E_2 is brought into circuit. The balancing length l_2 for cell E_2 is determined.Obviously,

$$E_2 \propto l_2$$

Hence, from equations, we get

$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$



Determination of Internal Resistance of a Cell

The circuit arrangement used is as shown. E is the cell whose internal resistance is to be measured.

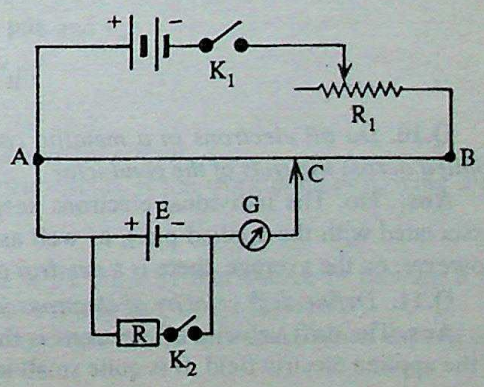
By adjusting the rheostat R_1 and closing key K_1, a balancing point is obtained on the potentiometer wire with K_2 open. Let the balancing length be l_1.

Now key K_2 is closed with a known resistance R out of box. Once again, without disturbing rheostat R_1, the balancing length is measured.

Let the balance length now be l_2.

Then, it is easy to see that $r = \left(\frac{l_1 - l_2}{l_2}\right) R$,

where r is the internal resistance of the cell E.



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SUBJECTIVE QUESTIONS ON UNIT - II

Q.1. *Define electric current.*

Ans. The current, flowing across any cross section of a conductor, equals the rate of flow of charge throu it, i.e., the charge crossing it normally in one second. Thus,

$$\text{Current} = \text{Charge} / \text{Time}$$

Q.2. *Define one ampere of current .*

Ans. The current, flowing across a cross section, equals one ampere, if one coulomb of charge crosses normally in one second.

Q.3. *Is current a scalar or a vector quantity?*

Ans. We take current to be a scalar quantity. [It is interesting to note that we treat current as a scal quantity even though we do talk of the direction of current flow. This is because we don't use the law of additi of vectors (the parallelogram law or the triangle law) to add two or more currents]

Q.4. *What constitutes electric current in a wire ?*

Ans. It is the organized (net) drift motion of electrons that constitutes an electric current in a wire.

Q.5. *Positive ions are moving from left to right. What is the direction of conventional current ?*

Ans. The direction of the conventional current will also be from *left to right, i.e.*, the direction in which t positive ions are moving.

Q.6. *What is the relation between conventional current direction and direction of motion of electrons?*

Ans. The direction of the conventional current is *opposite* to the direction of motion of electrons.

Q.7. *Why is there no electric current through a metallic conductor under normal conditions even when possesses a large number of free electrons ?*

Ans. A metal has a very large number of free electrons but these are normally moving at random in a possible directions. The net charge crossing any cross section in a finite time, therefore, becomes zero.

This is because as many electrons cross it in any one direction as in the opposite direction because of t random motion of the electrons. We, therefore, normally dc not have any electric current through a metall conductor, in spite of the presence of a large number of free electrons in it.

Q.8. *Why is it necessary to apply p.d. across its ends to have an electric current ?*

Ans. It is necessary to create some sort of orderliness (in the motion of the free electrons present in a meta to make the net charge, crossing any cross section, have a non-zero value. This is possible, only if there is som external force that forces the (otherwise randomly and chaotically moving) free electrons to move or drift in particular direction. An external electric field, directed in a particular direction, would achieve this aim. W therefore, apply a p.d. across the ends of the wire, (in which we want a current to flow) to 'create' such a fiel and , thereby, causes the electrons to drift in a particular direction.

Q.9. *How many electrons per second, would constitute a current of one micro- ampere ?*

Ans. Let n be the required number of electrons. We then have

$$n\,q = 10^{-6} \text{ coulomb / second}$$

$$\therefore \quad n = \frac{10^{-6}\,\text{C s}^{-1}}{1.6 \times 10^{-19}\,\text{C}} = \frac{10}{1.6} \times 10^{12}\,\text{s}^{-1} = \mathbf{6.25 \times 10^{12}\,s^{-1}}$$

Q.10. *Do all electrons in a metallic conductor drift in the same direction when a potential difference i applied across the ends of the conductor ?*

Ans. No. The individual electrons keep on drifting in the direction opposite to that of the electric field (associated with the applied p.d.), as well as suffering collisions and flying off again in all possible direction However, on the average, there is a *net drift* of the electrons in the direction opposite to that of the applied field.

Q.11. *Define drift velocity of electrons in a metallic conductor.*

Ans. The drift velocity of electrons is the average velocity acquired by them in a direction opposite to tha of the applied electric field. It is quite small in magnitude.

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Q.12. *What is the relation between electric current and drift speed of electrons in a metallic conductor ?* **(1)**

Ans. Let i be the current and v_d the drift velocity of the electrons. Then, $i \propto v_d$ and the complete relation is: $i = n e v_d A$. (Here n = number of free electrons per unit volume, e = charge of the electrons and A = area of cross section of the wire in which the current is flowing)

Q.13. *A steady current flows in a metallic conductor of non uniform cross section. State, which of the following quantities is constant along the conductor? current, current density, electric field, drift speed.* **(1)**

Ans. The current density (current per unit area of cross section) and the (average) drift speed are constant.

Q.14. *Why is that the electrons carrying current in a conductor move with a steady average drift speed even when they are experiencing a force?* **(2)**

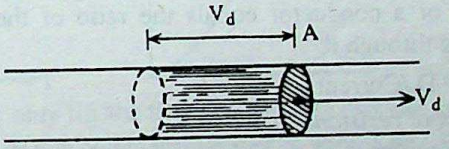
Ans. The electrons get accelerated, for a time τ, (the average time between collisions or the relaxation time) in the direction opposite to the field, then suffer a collision and fly off in a random direction. Their average drift velocity, in the direction opposite to the field, is then $\frac{eE}{m}\tau$.

Since τ is a constant at a particular temperature, the average drift velocity also remains constant.

Q.15. *Obtain a relation connecting the current flowing with the drift speed of the electrons.* **(2)**

Ans. Consider a wire of cross section A across which the electrons are drifting with an average (normal to the cross section) drift velocity v_d. We can then say that all the electrons contained in a cylinder of base area , A and 'height' v_d, are then able to cross the cross section A in one second. The total number of the electrons in this cylinder (volume = $A v_d$) is clearly nAv_d, where n is the number of free electrons per unit volume. Hence, the total charge crossing the cross section in one second, i.e., the current i is given by $i = (n A V_d) e$

This is the required relation.



Q.16. *Are the paths of electrons straight lines between successive collisions with the positive ions of the metal in the (i) absence of electric field and (ii) presence of electric field ?* **(2)**

Ans. (a) In the absence of an applied electric field, the motion of the electrons is random and chaotic and, therefore, their path between successive collisions are not straight lines.

(b) When an electric field is applied, the electrons drift, in a direction opposite to that of the applied field, between collisions. Hence, this path, between collisions are, on the average, straight lines.

Q.17. *How is that we are able to obtain large currents in a metal even though (i) the drift velocity acquired by the charge carriers and (ii) charge of the electrons are both very small ?* **(2)**

Ans. The current i is given by $i = n e v_d A$

Now both v_d and e are very small but n, the number density of free electrons, is very large. The overall product (nev_d) can, thus, be quite large in spite of the small values of e and v_d.

(Typically $v_d \sim 10^{-2}\ ms^{-1}$, $e \approx 1.6 \times 10^{-19}\ C$ and $n \approx 10^{23}/m^3$.

We, thus, have $n e v_d (\approx 1.6 \times 10^2) \approx 160\ C\ m^{-2}\ s^{-1}$)

Q.18. *Define the potential difference between two points in a electrical circuit.* **(1)**

Ans. The potential difference, between two points in an electric circuit, is the work done in moving a unit positive charge between these two points.

Q.19. *Define emf.*

Ans. The emf (electromotive force) of a 'source' equals the work done by that source in moving a unit positive charge around a closed path, starting and terminating at the 'starting end' of the 'source'.

For a cell, we define the emf of the cell as the potential difference between its terminals, when the cell is on an open circuit, i.e., when it is not supplying any current to any circuit.

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Q.20. *Why is a voltmeter always connected in parallel with a circuit element across which voltage is to be measured?* **(CBSE 1997 Comptt)** (1)

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Ans. As voltmeter is used to measure potential difference across an element and p.d. is same in parallel. Hence, voltmeter is always connected in parallel.

Q.21. *If the length of a wire conductor is doubled by stretching it, keeping the p.d. across it constant, by what factor does the drift speed of electrons change?* **(CBSE 1997 Comptt)** (1)

Ans. $v_d = \frac{eV}{ml}\tau$ If l is doubled keeping V constant, v_d is halved.

Q.22. *What is the difference between emf and terminal potential difference of a cell ?* (2)

Ans. The emf (E) of a cell is the potential difference between its terminals, when the cell is not supplying any current or is on an open circuit.

The terminal potential difference (V), on the other hand, is the potential difference between the cell terminals, when it is supplying a certain (finite) current I to a circuit of external resistance R.

The two are related by the relation :

$V = E - Ir$ where r is the internal resistance of the cell

Q.23. *Does emf have an electrostatic origin ?* (1)

Ans. No, the emf does not have an electrostatic origin, i.e., it is not associated with the electric fields produced by charges or charge distributions that are at 'rest'.

Q.24. *Does emf represent a force or potential energy or work done per unit charge ?* (1)

Ans. Emf does not represent either a force of potential energy. It is, in fact, work per unit charge.

Q.25. *Define resistance of a conductor.* (1)

Ans. The resistance of a conductor equals the ratio of the potential difference applied across it to the (resulting) current flowing through it.

Thus, Resistance = P.D./Current

Q.26. *Define one ohm of resistance.* (1)

Ans. The *ohm* is the resistance of a conductor through which a current of one ampere flows when a potential difference of one volt is applied across its ends.

Q.27. *Name the factors on which resistance of a conductor depends.* (1)

Ans. The resistance (R) of a conductor depends on (i) the nature of its material (ii) its length (l) and (iii) its area of cross section (A). We have $R = \rho \frac{l}{A}$ where ρ, known as the *resistivity*, is a characteristic of the material of the conductor.

Q.28. *What is conductance ? Give its S.I Units.* (1)

Ans. The reciprocal of the resistance of a conductor is known as its conductance. Thus, the conductance of a material equals the ratio of the current (i) flowing through it to the potential difference (V) applied across its ends. Thus, Conductance = Current/P.D.

The SI unit of conductance is $(ohm)^{-1}$, or mho, also known as the *siemen.*

Q.29. *State Ohm's law.* (2)

Ans. Refer to the 'Basic facts and formulae' on Unit 2.

Q.30. *Is Ohm's law universally applicable for all elements ?* (2)

Ans. No. Ohm's law is applicable only for a certain category of materials, particularly the metallic conductors.

Q.31. *Give examples of devices which do not obey Ohm's law.* (1)

Ans. We can cite the gas discharge tubes, semiconductors diodes, transistors,vacuum tubes, thermistors, etc., as examples of devices which do not obey Ohm's law.

Q.32. *State the conditions under which Ohm's law is not obeyed in a conductor.* (1)

Ans. Ohm's law will not be obeyed by a conductor, if there is a change in its physical conditions, e.g., its temperature, length, area of cross section, etc.

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Q.33. *Can we define 'resistance' only for those substances that obey Ohm's law ?* **(1)**

Ans. No. We can define the resistance (R) even of non-ohmic devices. In such cases, we define the (instantaneous) resistance as the rate of change of voltage with respect to current at each value of the applied voltage. Thus, in general,

$$R = Lt\left(\frac{\Delta V}{\Delta I}\right) = \frac{\partial V}{\partial I}$$

Q.34. *How does resistance of an ohmic conductor depend on the voltage ?* **(1)**

Ans. For an ohmic conductor, the resistance is a constant and, therefore, independent of the applied voltage.

Q.35. *What are non-ohmic devices ?* **(1)**

Ans. Any device that does not obey Ohm's law, is a non-ohmic device. Equivalently, we can say that if the characteristic current-voltage graph for a device is not a straight line, it is non-ohmic in nature.

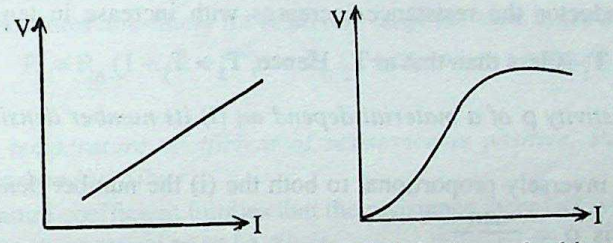
Q.36. *Define resistivity of a material.* **(1)**

Ans. The resistivity of a material equals the resistance of a unit length of a wire of the material of unit area of cross section.

Q.37. *What are S.I units of resistivity ?* **(1)**

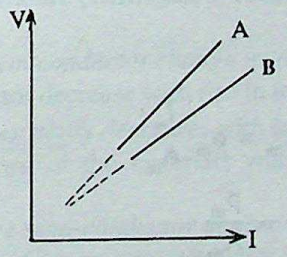
Ans. The SI unit of resistivity are ohm-metre ($\Omega - m$).

Q.38. *Fig. below shows V versus I graph of two materials. Which of the two obeys Ohm's law ?*



Ans. Since the V-I grapn is a straight line only for the first device, only this obeys Ohm's law.

Q.39. *Fig. below shows V versus I graph of two conductors A and B. Which one has higher resistance ?* **(1)**



Ans. The slope of the V-I graph (which equals the resistance) is more for conductor A. Hence, conductor A has a higher resistance than conductor B.

Q.40. *The p.d. across a conductor is doubled. The current increases by a factor of 3/2. Is conductor ohmic or non ohmic ?* **(1)**

Ans. The current is not increasing in the same ratio as the potential difference. Hence, the current is not directly proportional to the applied p.d. The conductor, therefore, does not obey Ohm's law, i.e., it is non-ohmic.

Q.41. *Define the term electrical resistivity of a material. How is it related to its electrical conductivity? Of the factors, length, area of cross section, nature of material and temperature, which one control the resistivity value of a conductor?* **(CBSE 1998) (2)**

Ans. The resistivity of a material equals the resistance of a unit length of a wire of the material of unit area of cross section.

$$\text{Electrical resistivity} = \frac{1}{\text{Electrical conductivity}}$$

Out of the given factors, resistivity only depends upon nature of material and temperature.

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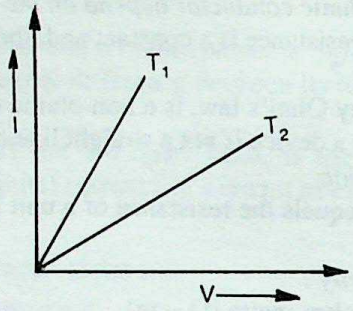
Q.42. *Name any one material having a small value of temperature coefficient of resistance. Write one use of this material.* **(CBSE 1997)** (2)

Ans. Constantan has a very small value of temperature coefficient of resistance. It is used for making standard resistors.

Q.43. *V-I graph for a metallic wire at two different temperatures T_1 and T_2 is as shown in the figure. Which of the two temperatures is higher and why?*



(CBSE 1998) (2)

Ans. For a metallic conductor the resistance increases with increase in temperature. In the graph, the resistance $\left(\frac{V}{I}\right)$ at temperature T_1 is less than that at T_2. Hence, $T_2 > T_1$.

Q.44. *How does the resistivity ρ of a material depend on (i) its number density n of free electrons (ii) its relaxation time τ ?*

Ans. The resistivity ρ is inversely proportional to both the (i) the number density n and (ii) the relaxation time, τ. The relevant formula is $\rho = \frac{2m}{e^2 n \tau}$

Q.45. *Two wires of equal lengths, one of copper and the other of manganin have the same resistance. Which wire is thicker ?* **(CBSE 1995)** (1)

Ans. We know that $R = \rho \frac{l}{A}$

$$\therefore \quad R_C = \rho_c \frac{l_c}{A_c} \text{ and } R_m = \rho_m \frac{l_m}{A_m}$$

Since, $R_C = R_m$ and $l_c = l_m$, we have $\frac{\rho_c}{A_c} = \frac{\rho_m}{A_m}$

$$\therefore \quad \frac{A_c}{A_m} = \frac{\rho_c}{\rho_m}$$

Since, $\rho_c < \rho_m$, we have $A_c < A_m$. Thus, the manganin wire is the thicker of the two.

Q.46. *A wire of length l and radius r has a resistance R. The wire is redrawn, so that its length is doubled. What is the resistance of redrawn wire?* (1)

Ans. The volume of the wire must remain unchanged. Hence,

$$l_1 A_1 = l_2 A_2$$

$$\therefore \quad \frac{A_1}{A_2} = \frac{l_2}{l_1} = 2$$

Thus, when the length is doubled, the area of cross section gets halved. Hence, the resistance will become

$$R' = \rho \cdot \frac{2l}{A/2} = 4\left(\rho \frac{l}{A}\right) = 4R$$

∴ The resistance *goes up* by a factor of 4.

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Q.47. *Why alloys, constantan and manganin are used to make standard resistance ?* (2)

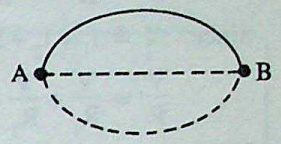
Ans. These alloys are preferred for making standard resistances because their

(i) resistivity is reasonably large, so that we do not need unduly long, or extra thin, wires for making resistances.

(ii) temperature coefficient of resistance is very low, so that small changes in temperature (associated with the flow of current) do not change their resistance to any significant extent.

Q.48. *A wire has a resistance of $1/\pi$ ohm m^{-1}. A circle of radius 1 m is made from this wire. What is the resistance between any two diametrically opposite points ?* (2)

Ans. We have two resistances, each of length equal to half the circumference, connected in parallel, between the two diametrically opposite ponts. Each resistance is $R = \left(\frac{1}{\pi} \text{ ohm m}^{-1}\right)(\pi \times 1 \text{ m}) = 1 \text{ ohm}$.



$\therefore$ The equivalent resistance, R_p is,

$$\frac{1}{R_p} = \frac{1}{1} + \frac{1}{1} \text{ or } R_p = \frac{1}{2} \text{ ohm} = 0.5\,\Omega$$

Q.49. *Discuss the temperature dependence of resistance for a conductor.* (2)

Ans. The resistance of a conductor increases with increase in temperature. The increase is linear for small increase in temperature but becomes non-linear for relatively large increase in temperature. We may say,

$$R_t = R_0 (1 + \alpha t + \beta t^2) \approx R_0 (1 + \alpha t), \text{ when t is small}$$

Of course $\beta << \alpha$.

Q.50. *For a material, temperature coefficient of resistance is positive. Pick up the material from the following : (i) Silicon (ii) Carbon (iii) Silver* (1)

Ans. A positive temperature coefficient implies that the resistance increases with an increase in temperature. This is true for metals. Hence, the material must be *silver.*

Q.51. *Is temperature coefficient of resistance positive or negative for pure germanium?* (1)

Ans. For pure germanium, the temperature coefficient of resistance is negative, i.e., the resistance decreases with an increase in temperature.

Q.52. *How does the resistivity of a semiconductor change with temperature ?* (1)

Ans. The resistivity of a semiconductor decrease with rise in temperature.

Q.53. *Name two substances whose resistivity decreases with increase in temperature.* (1)

Ans. Silicon and germanium are two of the materials whose resistance decreases with an increase in temperature.

Q.54. *What is the resistance of a pure semi-conductor at absolute zero of temperature ?* (1)

Ans. At absolute zero, the resistance of a pure semiconductor is infinite.

Q.55. *Give reasons for the low conductivity of electrolytes as compared to that of metals.* (2)

Ans. The conductivity of electrolytes is low compared to that of metals because.

(i) the number density of charge carriers in an electrolyte is quite low compared to that in metals.

(ii) the charge carriers in an electrolyte are both electrons and positive ions while those in a metal are only free electrons. The mobility (drift velocity per unit field) of the positive ions being quite low, compared to that of electrons, the presence of positive ions, also as charge carriers, leads to a further decrease in the conductivity of the electrolytes.

Q.56. *On a rheostat is written 2 amp (CONT) and 2.5 amp (INT). What do they mean ? Why is this difference in the two values of these currents ?* (2)

Ans. 2 amp (CONT) means that the rheostat can withstand a current of 2 A, even if the current flows continuously.

2.5 amp (INT) means that the rheostat can withstand a current of 2.5 A, only if this current flows for the short time intervals, i.e., intermittently.

The difference is there because the heat produced is directly proportional to the square of the current. The heat corresponding to a continuous current flow of 2 A would not damage the given rheostat, while that

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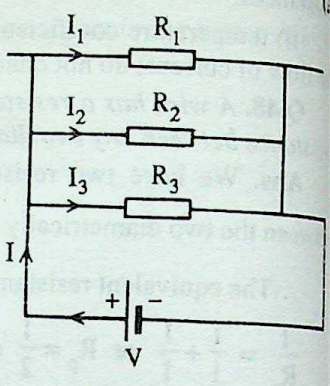
corresponding to 2.5 A would do so. A short spell of this current can still be tolerated because the rheos material would get a chance to cool between successive instants of heating.

Q.57. *Three resistances R_1, R_2 and R_3 are connected in parallel. Derive an expression for their equivale resistance R.*

Ans. Let a source of voltage V be connected across the parallel combination of R_1, R_2 and R_3. Let the resulting currents through the three resistances be I_1, I_2, I_3. We then have $I_1R_1 = I_2R_2 = I_3R_3 = V$



If I is the total current drawn from the source, we have, $I = I_1 + I_2 + I_3$.

If R is the equivalent resistance, we would have, $IR = V$

Hence, $I = \frac{V}{R}, I_1 = \frac{V}{R_1}, I_2 = \frac{V}{R_2}, I_3 = \frac{V}{R_3}$

Since, $I = I_1 + I_2 + I_3$, we have

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \quad \text{or} \quad \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

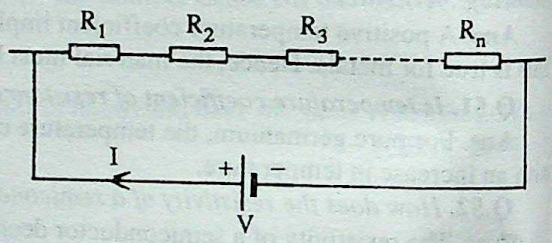
This is the relation for getting the equivalent resistance. The value of the equivalent resistance is

$$R = \frac{R_1 R_2 R_3}{(R_2R_3 + R_3R_1 + R_1R_2)}$$

Q.58. *Obtain an expression for the equivalent resistance of a number of resistances in series.* (2

Ans. Let a voltage source, of voltage V, be connected across the series combination of n resistances. Th current through all the resistances is the same and the sum of the p.d.'s across the individual resistances is V Hence,

$$V = IR_1 + IR_2 + \ldots + IR_n$$
$$= I(R_1 + R_2 + \ldots + R_n)$$



If R is the equivalent resistance,

we would have $V = IR$

Hence, $IR = I(R_1 + R_2 + \ldots + R_n)$

or $R = (R_1 + R_2 + \ldots R_n)$

This is the relation for getting the equivalent resistance of a number of resistances in series.

Q.59. *A wire of resistivity ρ is stretched to double its length. What will be its new resistivity ?* (1)

(CBSE 1995)

Ans. The resistivity will remain unchanged. This is because resistivity of a material is a characteristic of the material itself and does not depend on its length or diameter.

Q.60. *A copper wire of resistivity ρ is stretched to reduce its diameter to half of its previous value. What will be its new resistivity?*

Ans. The same as before. (See answer to Q no. 59 above) **(CBSE 1995 Comptt.)** (2)

Q.61. *Given n resistors each of resistance R. How will you combine them to get (i) maximum (ii) minimum effective resistance ?* (2)

Ans. (i) We must connect all the n resistances in series to get the maximum effective resistance,

(ii) We must connect all the n resistances in parallel to get the minimum effective resistance.

Q.62. *A potential difference V is applied across a conductor of length L and diameter D. How are the electric field E and the resistance R of the conductor affected, when in turn. (i) V is halved (ii) L is halved (iii) D is doubled.*

Ans. We know that $E = \frac{V}{L}$ and $R \propto \frac{L}{D^2}$ **(3) (CBSE 1997)**

(i) When V is halved, E is halved and R remains same.

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(ii) When L is halved, E is doubled and R is halved.

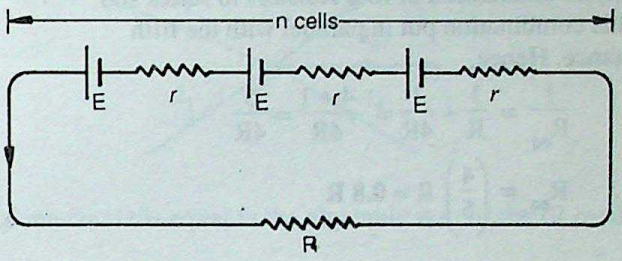
(iii) When D is doubled, E remains the same and R becomes $\frac{1}{4}$ th.

Q.63. *n identical cells of emf E and internal resistance r are connected in series to a resistor R.*

(i) Deduce an expression for the internal resistance r of one cell in terms of current I flowing through the circuit.

(ii) How does the internal resistance of a cell vary with temperature? **(CBSE 1997) (3)**

Ans. (i) Consider the figure below in which n identical cells of emf E and internal resistance r are connected in series with resistor R.



Here, local resistance of the circuit

$$= R + nr$$

Emf of the circuit = nE.

$$\therefore I = \frac{nE}{R + nr} \Rightarrow nE = I(R + nr)$$

$$\Rightarrow r = \frac{nE - IR}{In} = \frac{E}{I} - \frac{R}{n}$$

(ii) Internal resistance of a cell decreases with increase in temperature.

Q.64. *Define resistivity of a substance. Give its S.I. units. How does it vary with temperature for (i) good conductors (ii) ionic conductors (iii) semi-conductors?* **(CBSE 1997) (3)**

Ans. See answers to question no. 36, 37 for 1st part.

With increase in temperature the resistivity of

(i) good conductors increases.

(ii) ionic conductors decreases.

(iii) semi-conductors decreases.

Q.65. *Define resistivity of a conductor. Explain the variation of resistance with temperature in (i) metallic conductor (ii) semi-conductor.* **(CBSE 1999) (3)**

Ans. See answer to question no 36 for 1st part.

(i) The resistance of a metallic conductor increases with increase in temperature. It is because with increase in temperature, the frequency of collisions with atoms while drifting towards the positive end of the conductor also increases. This reduces the relaxation time τ.

(ii) For semi-conductors, the resistance decreases with increase in temperature. It is because the numbner of electrons increase in the conduction band due to greater generation of electron hole pairs.

Q.66. *A conductor of length l is connected to a d.c. source of potential V. If the length of the conductor is tripled by stretching it, keeping V constant explain how do the following factors vary in the conductor: (i) Drift speed of electrons (ii) Resistance and (iii) Resistivity.* **(CBSE 2000) (3)**

Ans. We know that drift-speed, $V_d = \frac{eV}{ml}\tau$ and resistance, $R = \rho\frac{l}{A}$

If the length, l is tripled then

(i) v_d becomes $\frac{1}{3}$ rd.

(ii) R becomes 3 times.

(iii) Resistivity remains unaffected.

Q.67. *Show that the equivalent resistance of n identical resistances each of resistance R when connected in parallel is R/n. Derive the formula used.* **(3)**

Ans. For derivation of the formula, see answer to Q. no. 57 above.

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Since, $R_1 = R_2 = R_3 = \ldots\ldots = R_n = R$, we have

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots\ldots \text{ n times} = \frac{n}{R}$$

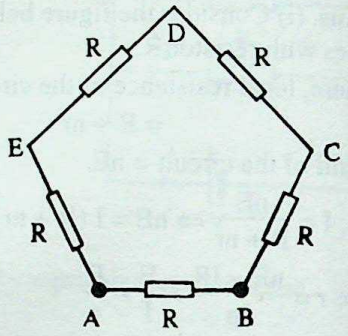
$$\therefore\ R_p = \frac{R}{n}$$

Q.68. *Five resistances, each of 5 Ω are arranged in the shape of a regular pentagon. What is the resistance between any two adjacent corners ?* (2)

Ans. We have the given arrangement equivalent to

(i) a combination of four resistors in series and

(ii) this combination put in parallel with the fifth resistance. Hence,



$$\frac{1}{R_{eq}} = \frac{1}{R} + \frac{1}{4R} = \frac{4+1}{4R} = \frac{5}{4R}$$

$$\therefore\ R_{eq} = \left(\frac{4}{5}\right) R = \mathbf{0.8\ R}$$

Q.69. *What are super conductors ?* (2)

Ans. Super conductors are materials whose resistance has become practically zero. This happens, in the case of metals, when they are cooled to very low temperatures. (Incidently, a superconductor is also a perfect diamagnetic.)

Q.70. *Is it possible to have super conductors at room temperature ?* (1)

Ans. No, so far it has not been possible to have super conductors at room temperature.

Q.71. *State Ohm's law. Show that the resistance of a conductor depends upon its shape.*

Ans. Refer to Q. no. 29 for statement of the law. **(CBSE 1994)** (1)

We know that $R = \rho \cdot \frac{l}{A}$ ρ is a constant for a given material while l and A depend on its shape. Hence, the resistance of a conductor depends on its shape.

Q.72. *Give the expression for the resistivity of a wire in terms of its material parameters, number density of free electrons and collision time*

Ans. The resistivity of a wire is given in terms of its number density (n) and collision time (τ) by the formula $\rho = \frac{2m}{n e^2 \tau}$ where m and e are the mass and charge of the charge carriers, the free electrons. **(CBSE 1994)** (1)

Q.73. *Define the term resistivity of a conductor. How does the resistivity of a conductor vary with temperature ?*

Ans. Refer to Q. No. 36 for definition of resistivity. **(CBSE 1993)** (2)

The resistivity of conductors increases with increase in its temperature.

Q.74. *A set of n identical resistors, each of resistance R ohm, when connected in series have an effective resistance of X ohm and when the resistors are connected in parallel, their effective resistance is Y ohm. Find the relation between R, X, and Y.*

Ans. We have, by law of resistors, in series and parallel. **(CBSE 1996)** (2)

$$X = R + R + \ldots\ldots \text{ n times} = nR \Rightarrow R = \frac{x}{n}$$

amd

$$\frac{1}{Y} = \frac{1}{R} + \frac{1}{R} + \ldots\ldots \text{ n times} = \frac{n}{R} \Rightarrow Y = \frac{R}{n}$$

Hence,

$$R = \frac{X}{n} = nY$$

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This is the relation between R, X and Y.

Q.75. *Of metals and alloys which has greater value of temperature coefficient of resistance?* **(CBSE 1995) (2)**

Ans. Generally, metals have a higher value of the temperature coefficient of resistance. (We can have alloys like manganin or constantan for which the temperature coefficent of resistance is practically zero).

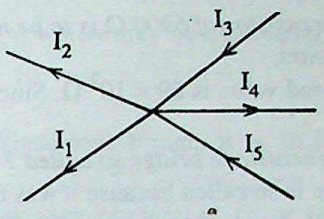
Q.76. *How does conductivity of a semi-conductor change with temperature ?* **(CBSE 1995) (2)**

Ans. The conductivity of a (pure) semi-conductor increases with an increase in its temperature.

Q.77. *State Kirchoff's laws for electrical circuits.* **(CBSE 1993) (2)**

Ans. According to Kirchoff's first law :

The algebraic sum of all the currents, flowing towards a junction point, is zero. Thus, $\sum_{j=1}^{n} I_j = 0$



According to Kirchoff's second law :

The algebraic sum of the emf's in any loop of a given circuit is equal to the algebraic sum of the IR products in it. Thus,

$$\sum E_j = \sum I_j R_j$$

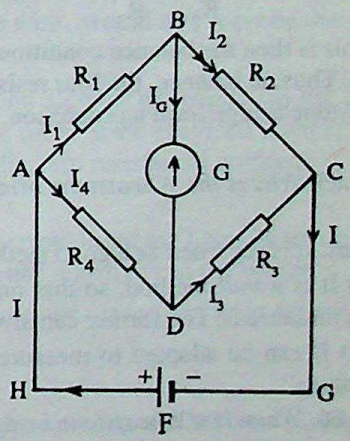
Q.78. *Explain, how Kirchoff's laws help us in analysing d.c. networks containing resistances and sources of emf* **(3)**

Ans. To analyse a given circuit, we need to know the current flowing in each branch of the circuit. For this, we need as many independent equations as is the number of the unknown currents. Kirchoff's laws help us in getting these required equations.

(i) First use the *current law* to write the possible number of independent equations, using the various junction points in the circuit.

(ii) Next, use the voltage law to write the remaining required number of independent equations, using the appropriate 'loops' in the circuit.

We illustrate this technique of writing the requisite number of equations, using Kirchoff's laws by considering the case of the Wheatstone bridge.



Using the *current law,* we have

At junction A : $I - I_1 - I_4 = 0$

At junction B : $I_1 - I_2 - I_G = 0$

At junction C : $I_2 + I_3 - I = 0$

(we do not consider the junction D as the equation we get therefrom, is not independent of these three equations).

We next use the voltage law. Here, we have

For the loop ABDA : $I_1 R_1 + I_G G - I_4 R_4 = 0$

For the loop BC DB : $I_2 R_2 - I_3 R_3 - I_G G = 0$

and for the loop ABCGHA : $I_1 R_1 + I_2 R_2 - E = 0$

We, thus, get six independent equations for the six unknown currents (I, I_1, I_2, I_3, I_4 and I_G).

These can be solved to get the current values. Once these values are obtained, we consider the circuit to be 'analysed.'

Q.79. *The sequence of bands marked on a carbon resistor is yellow, red, orange and silver. What is its resistance and tolerance ?* **(2)**

Ans. We have yellow = 4, red = 2 and orange = 3. Also silver means a tolerance of ± 10 %.

Hence, the value of the resistor is $(42 \times 10^3 \pm 10\ \%)\ \Omega = (42\ k\Omega \pm 10\ \%)$

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Q.80. *On a given resistor, the colour bands are in the sequence, green, violet and red. What is the resistance ?* (1)

Ans. We have green = 5, violet = 7 and red = 2. There being no fourth colour band, the tolerance is $\pm 20\ \%$. Hence, the value of the resistor is $(57 \times 10^2 \pm 20\ \%)\ \Omega = (5.7\ \text{k}\ \Omega \pm 20\ \%)$

Q.81. *A carbon resistor of 47 k Ω is to be marked with rings of different colours for its identification. Write the sequence of colours.* (1)

Ans. The required value is $47 \times 10^3\ \Omega$. Since 4 = yellow, 7 = violet and 3 = orange, the required sequence of colour bands is yellow, violet, orange.

Q.82. *A carbon resistor of 6900 Ω is to be marked with rings of different colours for its identification. Write the sequence of colours.* (1)

Ans. The required value is $69 \times 10^2\ \Omega$. Since 6 = blue, 9 = white and 2 = red, the required sequence is blue, white and red.

Q.83. *Why is Wheatstone bridge so called ?* (1)

Ans. The bridge is so called because it was first designed and used by Prof. Wheatstone.

Q.84. *Draw a diagram of Wheatstone's bridge. Obtain the condition of balance.* (3)

Ans. The Wheatstone bridge is shown below. At balance, $I_g = 0$. Hence, using Kirchoff's first law at junction points B and D, we get $I_1 = I_2$ and $I_3 = I_4$.

Again applying Kirchoff's second law to the meshes ABDA and BCDB, we have, at balance (i.e., when $i_g = 0$),

$$I_1R_1 - I_4R_4 = 0 \quad \text{or} \quad I_1R_1 = I_4R_4$$

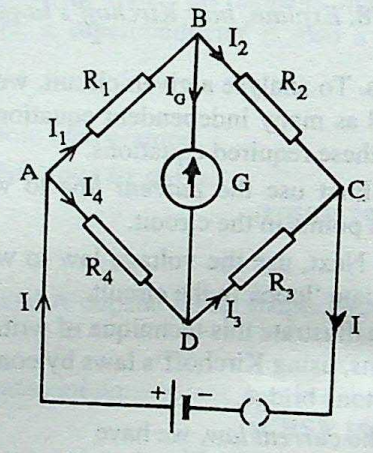
and $$I_2R_2 - I_3R_3 = 0 \quad \text{or} \quad I_2R_2 = I_3R_3$$

Hence, $$\frac{I_1R_1}{I_1R_2} = \frac{I_4R_4}{I_3R_3}$$

or since, $I_1 = I_2$ and $I_4 = I_3$, at balance, we have

$$\frac{R_1}{R_2} = \frac{R_4}{R_3}$$

This is then the balance condition for a Wheatstone bridge. Thus, at balance, the four resistor arms of a Wheatstone bridge form a proportion.



Q.85. *Why is the Wheatstone bridge regarded as a good method for measurement of resistances ?* (2)

Ans. It is regarded as a good method for measurements of resistances because:

(i) It is a *null* method, so that one has to simply defect the absence of any galvanometer deflection rather than to measure it. The former can always be done with greater accuracy and convenience

(ii) It can be adapted to measure resistances over a fairly wide range-from moderately low to reasonably high values.

Q.86. *When is a Wheatstone bridge set up more sensitive ?* (2)

Ans. A Wheatstone bridge set up is more sensitive when all its four arm resistors, as well as the galvanometer resistance, are nearly of the same order.

Q.87. *Deduce an expression for the determination of an unknown resistance using a Wheatstone bridge.* (3)

Ans. Refer to Q. No. 84 above for deduction of the balance condition of a Wheatstone bridge.

Since, the balance condition is $\frac{R_1}{R_2} = \frac{R_4}{R_3}$, we have $R_4 = \frac{R_1}{R_2} \cdot R_3$. Hence, if we can adjust the three known resistances, R_1, R_2 and R_3, to bring the Wheatstone bridge to its balance condition, we can calculate the fourth unknown resistance (R_4).

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Q.88. *Can we measure very low resistances with the help of ordinary Wheatstone bridge?* **(1)**

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Ans. No, (an ordinary) Wheatstone bridge is not very suitable for measurements of low resistances [However, its slightly 'modified form' such as the Carey Foster bridge, can be used for this purpose with reasonable accuracy.]

Q.89. *Can we measure a resistance of the order of few mega ohms using a Wheatstone bridge ?* **(1)**

Ans. No, a Wheatstone bridge is not suitable for measurements of very high resistances of the order of megaohms. [The bridge is not sensitive for such high resistance values].

Q.90. *In the Wheatstone bridge method, why do we close the battery circuit first and then the galvanometer circuit ?* **(2)**

Ans. This is done to avoid the effects of self induced emf's, which may be associated with any inductive element present in any of its four arms.

Q.91. *What is the principle of a meter bridge ?* **(1)**

Ans. The meter bridge is based on the principle of the Wheatstone bridge. It is, in fact, one of the two practical forms of the Wheatstone bridge.

Q.92. *How will you use a metre bridge to measure an unknown resistance? Draw the necessary circuit diagram. Explain the principle of the experiment. Give the formula used.* **(CBSE 1997) (3)**

Ans. See text under the heading 'The meter bridge'.

Q.93. *Why should the balance point be near the middle point of the meter bridge wire ?* **(1)**

Ans. The balance point should be near the middle of the meter bridge becaue that (i) makes the bridge more sensitive by making the resistances of the same order. (ii) decreases the possible relative error in the measurements of the balancing length (s). The error would be more, if the balance point is near either end of the wire.

Q.94. *Why should the area of cross section of meter bridge wire be uniform ?* **(2)**

Ans. We assume the resistance per unit length, of the meter bridge wire to be constant, all over its length. This is possible, only if the wire has a uniform cross section throughout.

Q.95. *Why is it not advisable to have the null point near one end of the meter bridge wire ?* **(1)**

Ans. It is not advisable to have the balance point near either end of the meter bridge as then both the advantages, associated with having the balance point near the middle of the wire, would no longer be there.

Q.96. *What are the main errors in a meter bridge ?* **(2)**

Ans. The possible errors are (i) the wire is not of uniform cross section all over its length. (ii) the ends of the wire are not coincident with the 'zero' and the '100 cm' mark of the meter scale provided alongside. (iii) the contacts of the wire, with the thick copper strips, are not good (practically zero resistance) contacts.

Q.97. *How can the accuracy of a meter bridge be increased ?* **(2)**

Ans. The accuracy of a meter bridge can be increased by avoiding the errors listed in Q.No. 96 above. Also, we should keep the resistors in the four arms of the same order to have a better sensitivity of the bridge.

Q.98. *Name any set up-other than the meter bridge based on the Wheatstone bridge and used for resistance measurement purposes.* **(1)**

Ans. Another such set up is the 'post office box'.

Q.99. *Deduce an expression for the determination of an unknown resistance using a Wheatstone bridge.* **(CBSE 1994 Comptt) (3)**

Ans. Refer to Q.no. 84.

Q.100. *Draw a circuit diagram for comparing two resistances using a meter bridge. Write the principle of the experiment. Why is this method suitable for two resistances of the same order of magnitude ?* **(CBSE 1993 Comptt.) (3)**

Ans. The circuit diagram is as shown.

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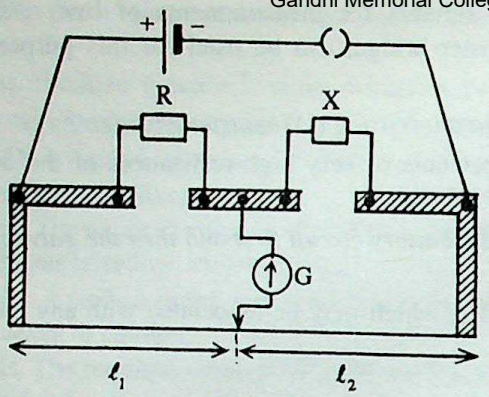
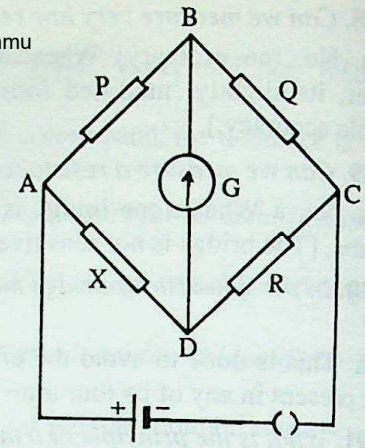




The principle of the experiment is the principle of the Wheatstone bridge. According to the principle :

Let there be four resistances P, Q, R and X and a galvanometer and cell arranged as shown. Let the values of the four resistances be so adjusted that there is no current in the galvanometer arm. Then,

$$\frac{P}{Q}=\frac{X}{R} \text{ or } X=\frac{P}{Q}\cdot R$$

We can use this relation to calculate X.

The method is suitable for two resistances of the same order of magnitude because then

(i) the bridge works in a more sensitive manner; (ii) the balance point is obtained near the centre of the wire so that the errors due to non-uniformity, etc., of the wire are minimized.

Q.101. *Explain, with the help of a circuit diagram, how the value of an unknown resistance can be determined using a Wheatstone bridge. Give the formula used.* **(CBSE 1996)** (3)

Ans. Refer to Q.No. 84, 87 and 100.

Q.102. *Draw a circuit diagram of a meter bridge arrangement to compare two resistances. Explain the principle of the experiment and give the formula used.* **(CBSE 1995 Comptt.)** (3)

Ans. See Q. No. 100 for the required circuit diagram, the principle of the experiment.

The formula used in a meter bridge is $\frac{R}{X}=\frac{l_1}{l_2}$ or $X=\frac{l_2}{l_1}R$

Q.103. *You are required to determine the specific resistance (resistivity) of the material of a wire in the laboratory. Draw the circuit diagram. Explain the principle of the experiment. Give the formula used.* **(CBSE 1995 Comptt.)** (3)

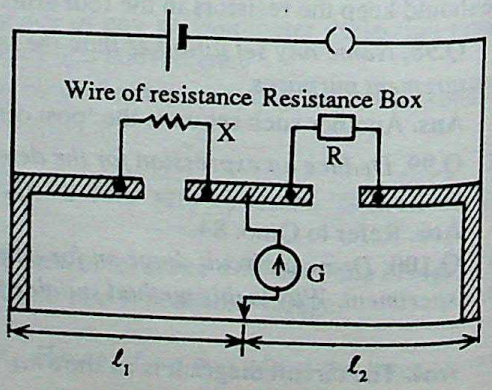
Ans. We first notice that the resistance X of a wire of length L and area of cross section A is given by $X=\rho\frac{L}{A}$ where ρ is the resistivity of the material. Now $A=\pi r^2=\pi\frac{d^2}{4}$, where r and d stand for the radius and diameter of the wire respectively. Hence,

$$\rho=X\cdot\frac{A}{L}=X\frac{\pi d^2}{4L}$$

The diameter of the wire can be measured by using a screw gauge while its length can be determined using a meter scale. The resistance can be determined using a meter bridge. The circuit diagram is shown above.

The principle, as explained above, in Q.no. 100, is that of the Wheatstone bridge. The relevant formula is

$$\frac{X}{R}=\frac{l_1}{l_2}$$



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or $X = R \cdot \frac{l_1}{l_2}$

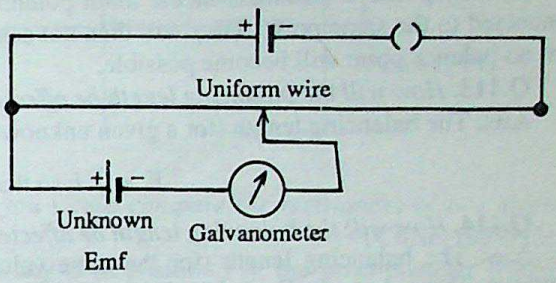
We, thus, get ρ from the formula $\rho = \left(R \cdot \frac{l_1}{l_2}\right) \cdot \frac{\pi d^2}{4L}$

Q.104. *What is the principle of a potentiometer ?* **(2)**

Ans. A potentiometer works on the following principle :

(i) The potential drop per unit length of a uniform wire (connected to a source of emf) is directly proportional to the length of the wire.

(ii) We can detect the equality of two emf's by making them send currents in opposite directions through a current detector, like the galvanometer.



Q.105. *What is the 'potential gradient' in a potentiometer* **(1)**

Ans. The potential gradient equals the potential difference per unit length of the potentiometer wire.

Q.106. *Can we use a voltmeter for the measurement of the emf of a cell ?* **(1)**

Ans. No, not exactly, unless the voltmeter is an ideal (infinite resistance) voltmeter. The usual (finite resistance) voltmeters measure only the terminal p.d. (=E–ir) of the cell.

Q.107. *How is the potentiometer compared with the voltmeter as a method for measurement of potential differences ?* **(2)**

Ans. The potentiometer is more accurate because it is a *null* method. The voltmeter, on the other hand, works on the basis of measurement of a deflection

Q.108. *Should we increase or decrease the potential gradient to increase the sensitivity of the potentiometer set up ?* **(2)**

Ans. We should decrease the potential gradient (potential drop per unit length) of a potentiometer to increase its sensitivity. A smaller potential gradient implies a smaller value of the *'least count'* of the potentiometer and, therefore, a better sensitivity.

Q.109. *How can we decrease the value of the potential gradient for a potentiometer ?* **(2)**

Ans. We can decrease the value of the potential gradient, for a potentiometer, by either.

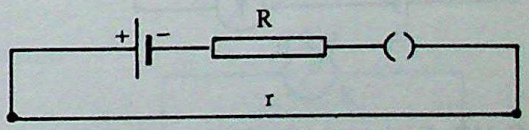
(i) decreasing the emf of the 'main battery' connected across the potentiometer wire.

or (ii) adding a suitable (high) resistance in series with the potentiometer wire.

In either case, however, we must ensure that the total p.d. over the whole length of the potentiometer wire, is greater than the unknown emf

Q.110. *Obtain an expression for the potential gradient 'k' of a potentiometer whose wire of length l has a resistance r. The driving cell has an emf E and is connected in series with an external resistance R.* **(2)**

Ans. The set up suggested is shown in the circuit diagram drawn here. The current through the potentiometer wire is then



$$i = \frac{E}{R + r}$$

The p.d. across the whole length of the potentiometer wire is then $(= ir) = \frac{E \cdot r}{R + r}$. This is the potential drop over a length L of the wire. Hence, the potential gradient (k), i.e., the potential drop per unit length of the wire is

$$k = \frac{1}{L} \cdot \frac{Er}{(R + r)} = \frac{Er}{(R + r)L}$$

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Q.111. *Why do we prefer a 'ten' wire potentiometer to a 'four' wire potentiometer ?*

Ans. When we increase the number of potentiometer wires, the potential gradient (for the same emf of the main battery) goes down. This implies a better sensitivity of the potentiometer. Hence, the ten wire potentiometer is regarded as better than the four wire potentiometer. (3)

Q.112. *Sometimes a balance point may not be obtained on the potentiometer wire. Why ?*

Ans. The balance point will not be obtained under either of the following two situations : (3)

(1) The 'emf' of the main potentiometer battery may be less than the unknown emf

(2) The positive terminals of the main potentiometer battery and the source of the unknown emf are not connected to the same point. They will then not send current through the galvanometer in opposite directions so that no balance point will become possible.

Q.113. *How will the balancing length be affected by a decrease of its potential gradient ?*

Ans. The balancing length (for a given unknown emf, say E) will increase. This is because (1)

$$E = k\,l \text{ so that } l \propto \frac{1}{k} \text{ (for a given E).}$$

Q.114. *How will the balancing length be affected by a decrease of the p.d. to be measured ?*

Ans. The balancing length (for the same value of the potential gradient of the potentiometer wire) will decrease. This is because $E = k\,l$ so that $l \propto E$ (for a given 'k'). (1)

Q.115. *How will the position of the null point be affected by a decrease in the emf of the driving cell of the potentiometer ?*

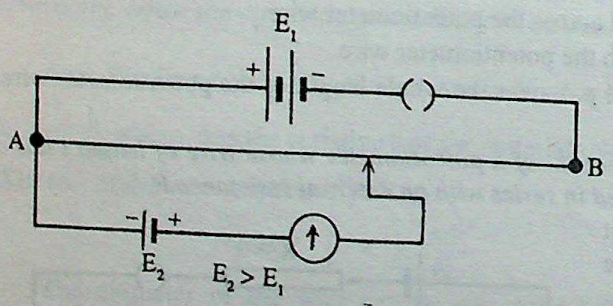
Ans. When the emf, of the driving (main) cell of the potentiometer, is decreased, the potential gradient (k) also goes down. Hence, the null point *will move ahead* (i.e., the balancing length will increase), for a given unknown emf. (1)

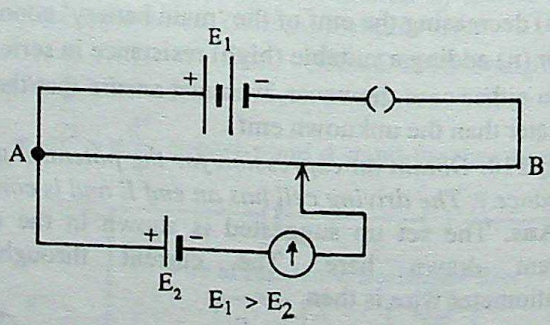
Q.116. *How will the position of the null point be affected by using a potentiometer wire of smaller length ?*

Ans. For the same driving cell, a decrease in the length of the potentiometer wire, will cause an increase in its potential gradient (k = E/L). Hence, the balancing length will decrease, for a given unknown emf. (1)

Q.117. *It is observed that the deflection in a potentiometer set up is in the same sense both at the starting end as well as at the other extreme end of the potentiometer. However, the value of this deflection is more at the other extreme end than at the starting end. What could be the reason for this ? How can it be corrected ?*

Ans. The deflection is in the same sense at both the ends but its value is *less* at the other extreme than at the starting end. This means that the main emf (or the emf of the driving cell) and the unknown emf are indeed opposing each other. However, the main emf is less than the unknown emf so that it is not able to balance, if even when the jockey is taken to the other extreme. We must, therefore, increase the main (driving cell) emf to correct the circuit. (3)





Q.118. *Explain the working principle of a potentiometer. How will you find the value of the emf of an electric cell using a potentiometer ?*

Ans. The working principle of the potentiometer has been explained above in Q.no. 104. (3)

To find an unknown emf, we make the connections as shown. Here E_x is the unknown emf and E_s is a (known) standard emf We put the *'two way key'* in the position (1) (which connects E_x to the potentiometer circuit) and find the balancing length l_1. Next the two way key is put in the position (2) (which connects E_s to the potentiometer circuit) and the balance length l_2 is found. Then, for a (constant) potential gradient 'k' we have

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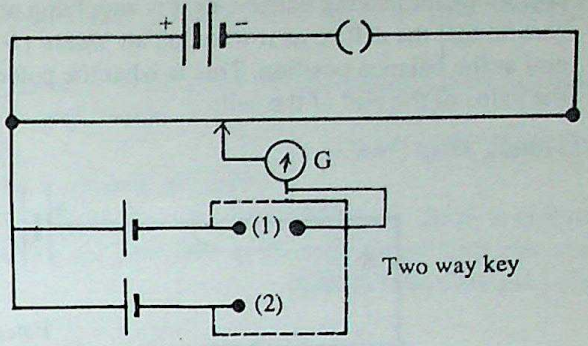
$E_x = k\,l_1$ and $E_s = k\,l_2$

$$\therefore \quad \frac{E_x}{E_s} = \frac{l_1}{l_2} \quad \text{or} \quad E_x = E_s \cdot \frac{l_1}{l_2}$$

Thus, E_x can be found out. We have to be, however, very careful while working with the standard cell E_s. All its relevant precautions must be carefully observed to avoid any damage to it.



Q.119. *With the help of a circuit diagram, explain how you would compare the resistances of two given resistors using a potentiometer.* **(CBSE 1993) (3)**

Ans. The circuit is set up as shown. When the two way key is in position (1), the potentiometer would balance the p.d. across the resistor R_1 only. If the balance length is l_1, we would have

$$i\,R_1 = k l_1$$

Here i is the current though the series combination of R_1 and R_2 and k is the potential gradient of the potentiometer wire.

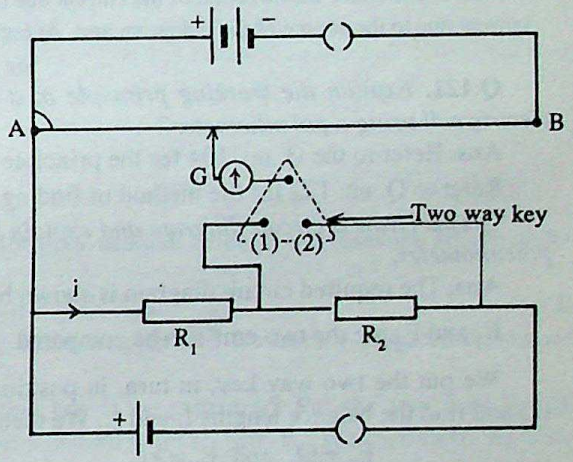
The two way key is now put in the position (2). The potentiometer wire now has to balance the total p.d. across the series combination of R_1 and R_2. Hence, if the balance length now is l_2, we would have

$$i\,(R_1 + R_2) = k\,l_2$$

$$\therefore \quad \frac{R_1 + R_2}{R_1} = \frac{l_2}{l_1} \quad \text{or} \quad 1 + \frac{R_2}{R_1} = \frac{l_2}{l_1}$$

$$\text{or} \quad \frac{R_2}{R_1} = \left(\frac{l_2}{l_1} - 1\right) \quad \therefore \quad \frac{R_1}{R_2} = \frac{l_1}{(l_2 - l_1)}$$

We can use this relation to compare the two unknown resistances.



Q.120. *A potentiometer can measure emf of a cell, while the voltmeter cannot. Explain giving reasons.* **(3)**

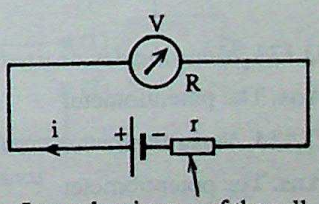
Ans. The emf (E) of a cell equals the potential difference between its terminals, when the cell is on an *open circuit,* i.e., not supplying any (net) current. We, however, measure only the terminal p.d. (V) across the cell, when it is supplying some current i to an (finite) external resistor R. The relation between E and V is V = E – ir, where r is the internal resistance of the cell.

Consider now the case when a voltmeter is being used to measure the 'emf' of a cell. The cell will have to supply a current i where

$$i = \frac{E}{R + r}$$

Here R is the resistance of the cell. Hence, the terminal p.d. across the cell, which is also the p.d. across the voltmeter terminal, is

$$V = iR = \frac{ER}{R + r}$$



Internal resistance of the cell

This cannot equal E unless r is equal to zero. This is never (strictly) true in practice so that the voltmeter cannot measure the emf of the cell.

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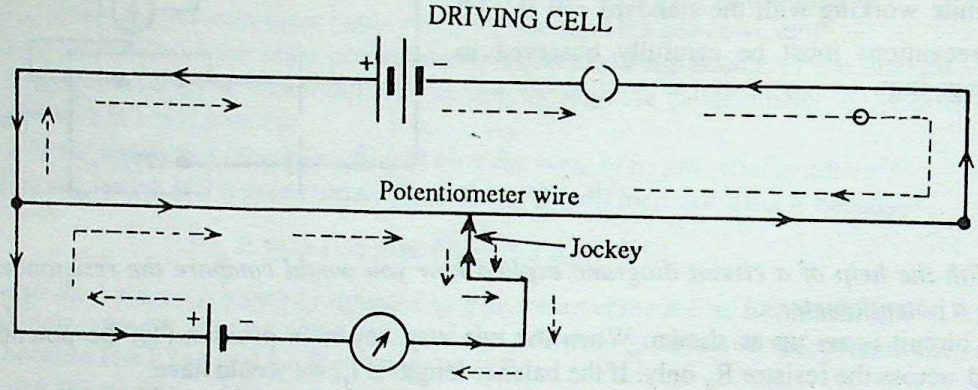
Consider next a potentiometer circuit. Here, at balance, the cell gets back as much current from the potentiometer driving battery, as it is supplying at that instant. The net current drawn from the cell is, therefore, zero so that the cell is, as it were, on an *'opern circuit'*. The terminal p.d. across the cell is, therefore, equal to emf at the balance position. This is what the potentiometer measures. The potentiometer is, thus, able to give the value of the emf of the cell.



Solid arrows indicate the direction of the current due to the driving cell while the dotted line arrows give the direction of the current due to the source of the unknown emf. At balance, the values of the these two currents, through the galvanometer, are equal and opposite

Q.121. *Explain the working principle of a potentiometer. How will you find the value of the emf of a electric cell using a potentiometer?* **(CBSE 199**

Ans. Refer to the Q. no. 104 for the principle of the potentiometer.

Refer to Q. no. 122 for the method of finding the unknown emf of a cell.

Q.122. *Draw a circuit diagram and explain how the emf of the two primary cells can be compared using potentiometer.* **(CBSE 1994, 2000) (**

Ans. The required circuit diagram is shown below.

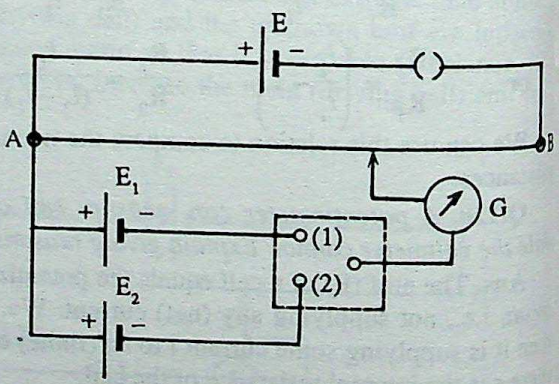
E_1 and E_2 are the two emf's to be compared.

We put the two way key, in turn, in position (1) and (2) and find the balance lengths l_1 and l_2. We then have

$$E_1 = kl_1 \text{ and } E_2 = kl_2$$

$$\therefore \frac{E_1}{E_2} = \frac{l_1}{l_2}$$

The two emf's can, thus, be compared in terms of the ratio of the two balancing lengths.



Q.123. *Name the device used for measuring the internal resistance of a secondary cell.* **(CBSE 1996) (1**

Ans. The potentiometer

Q.124. *Name the device used for measuring the emf of a cell.* **(CBSE 1996) (1**

Ans. The potentiometer

Q.125. *Why potentiometer is preferred over voltmeter for measuring emf?* **(CBSE 1999) (1**

Ans. A potentiometer does not draw any current from the cell whose emf is to be determined, whereas the voltmeter always draws some current. Hence, emf measured by voltmeter is slightly less than the actual value of emf of the cell.

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Q.126. *Explain the principle on which the working of a potentiometer is based. Why is the use of potentiometer preferred over that of a voltmeter for measurement of emf of a cell?* **(CBSE 1998) (2)**

Ans. See answer to questions 104 and 125.

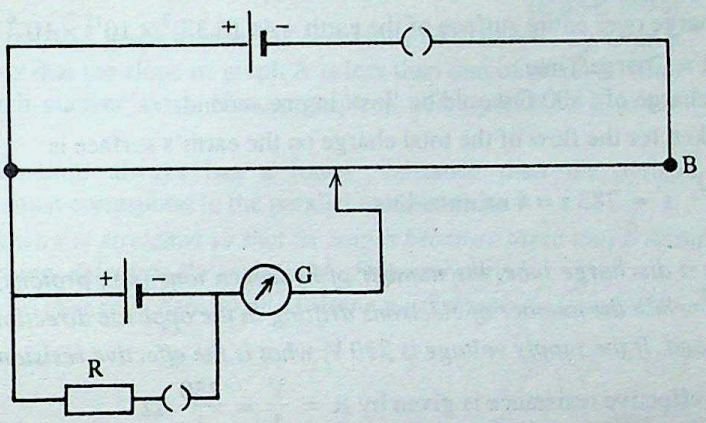
Q.127. *Explain with the help of a circuit diagram, the use of potentiometer for determination of internal resistance of a primary cell. Derive the necessary mathematical expression.*

(CBSE 1998, 2000) (3)

Ans. See text under the heading "Determination of internal resistance of a cell".

Q.128. *You are required to find the internal resistance of a primary cell in the laboratory. Draw a circuit diagram of the apparatus you will use to determine it. Explain the principle of the experiment and give the formula used.* **(CBSE 1995 Comptt.) (3)**

Ans. The required circuit diagram is shown below.



For details of the principle of the experiment and the formula needed, refer to the relevant article under 'Basic facts and formulae on Unit 2.

Q.129. *Can we use a potentiometer for measuring currents ? If so, how ?* **(2)**

Ans. Yes. We can use the potentiometer for measuring currents, provided we have a standard resistance available with us. The required circuit is shown below.

Let i be the current (through the standard resistance) that has to be measured. Put the two way key in position (1) and find the balance length, l_1 corresponding to the standard emf (known) E_1. We then have $E_1 = kl_1$

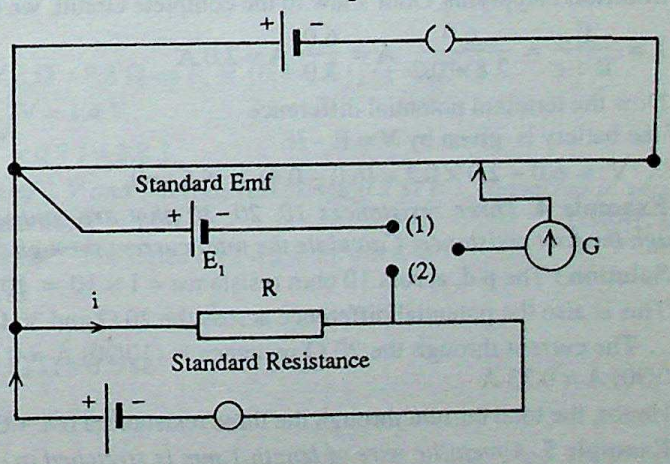
Next put the two way key in position (2) and find the balance length, l_2, corresponding to p.d. (= iR) across the standard resistance R.

We then have

$$iR = kl_2$$

$$\therefore \quad \frac{iR}{E_1} = \frac{l_2}{l_1} \quad \text{or} \quad i = \frac{l_2}{l_1} \cdot \frac{E_1}{R}$$

We can, thus, calculate the value of the (unknown) current.



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SOLVED NUMERICAL PROBLEMS ON UNIT II

Example 1. *The earth's surface has a negative surface charge density of 10^{-9} cm^{-2}. The potential difference of 400 kV between the top of the atmosphere and the surface results (due to the low conductivity of the lower atmosphere) in a current of only 1800 A over the entire globe. If there were no mechanism of sustaining atmospheric electric field, how much time (roughly) would be required to neutralize the earth's surface? Given radius of earth = 6370 km.*

Solution : Surface charge density of earth = 10^{-9} cm^{-2}

Radius of the earth = 6370 km = 6.37×10^6 m

$\therefore$ Total surface area of earth = $4\pi\,(6.37)^2 \times 10^{12}$ m^2

Hence, total charge over entire surface of the earth = $4\pi\,(6.37)^2 \times 10^{12} \times 10^{-9}$ C

Since, Current = Charge/Time,

we find that a charge of 1800 C would be 'lost' in one second.

Hence, time taken for the flow of the total charge on the earth's surface is

$$\frac{4\pi\,(6.37)^2 \times 10^3}{1800}\ \text{s} \approx 283\ \text{s} = \textbf{4 minute 43 s.}$$

Example 2. *In a discharge tube, the number of hydrogen ions (i.e., protons) drifting across a section per second is 1.0×10^{18} while the number of electrons drifting in the opposite direction across another cross section is 2.7×10^{18} per second. If the supply voltage is 230 V, what is the effective resistance of the tube?*

Solution : The effective resistance is given by $R = \dfrac{V}{I} = \dfrac{230}{I}\ \Omega$

To calculate the current I, we note that the current due to the drifts of the protons in one direction and the electrons in opposite direction simply *add up* to give us the total current. Hence,

$$I = (n_p e + n_e e)$$

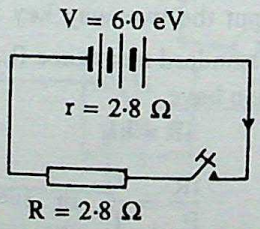
$$= [(1.0 + 2.7) \times 10^{18}] \times 1.6 \times 10^{-19}\ A = 3.7 \times 1.6 \times 10^{-1}\ A = 0.592\ A$$

$\therefore$ $R = (230/0.592)\ \Omega = \textbf{388.51}\ \Omega$.

Example 3. *A battery of emf 6.0 V and internal resistance 0.2 Ω is connected to an external resistance of 2.8 Ω. Calculate the terminal potential difference of the battery.*

Solution : Applying Ohm's law to the complete circuit, we have

$$I = \frac{E}{R + r} = \frac{6.0}{2.8 + 0.2}\ A = \frac{6.0}{3.0}\ A = 2.0\ A$$



Now the terminal potential difference V of the battery is given by $V = E - Ir$

$\therefore$ $V = 6.0 - 2.0 \times 0.2 = (6.0 - 0.4) = \textbf{5.6 volt.}$

Example 4. *Three resistances 10, 20, 30 ohm are connected in parallel. A current of 1 ampere passes through the first resistance. Calculate the total current through the resistances.*

Solution : The p.d. across 10 ohm resistance = $1 \times 10 = 10$ V

This is also the potential difference across the 20 Ω and 30 Ω resistors.

$\therefore$ The current through the 20 Ω resitance is (10/20) A = 0.5 A and the current through the 30 Ω resistance is (10/30) A = 0.33 A

Hence, the total current through the three resistances is 1 + 0.5 + 0.33 = **1.83 A.**

Example 5. *A metallic wire of length 1 mm is stretched to double its length. Calculate the ratio of the final resistance assuming that there is no change in density on stretching.* **(CBSE 1994)**

Solution : Since, there is no change in density, the volume must remain constant.

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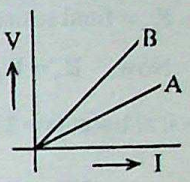
Hence, $A_1 l_1 = A_2 l_2$ or $\frac{A_1}{A_2} = \frac{l_2}{l_1} = 2$

Now, $R_1 = \frac{\rho l_1}{A_1}$ and $R_2 = \frac{\rho l_2}{A_2}$

$\therefore \quad R_2/R_1 = \frac{l_2}{l_1}\frac{A_1}{A_2} = 2 \times 2 = 4$

The resistance, therefore, becomes **4** times its original value.

Example 6. *V – I graphs for parallel and series combination of two metallic resistors are as shown in the figure. Which graph represents the parallel combination? Justify your answer.* **(CBSE 1994)**



Solution : The slope of the V–I graph represents resistance ($\Delta V/\Delta I = R$, by Ohm's law). From the figure, it is clear that the slope of graph A is less than that of graph B. (line A makes a smaller angle with current axis). Hence, graph A corresponds to a lower resistance than graph B.

Now the parallel combination always has a lower resistance than the series combination. Hence, graph A must correspond to the parallel combination.

Example 7. *A 10 Ω thick wire is stretched so that its length becomes three times. Assuming that there is no change in its density on stretching, calculate the resistance of the new wire.* **(CBSE 1994)**

Solution : Since, there is no change in density, the volume must remain constant. Hence, $A_1 l_1 = A_2 l_2$

$\therefore \quad \frac{A_1}{A_2} = l_2/l_1 = 3$

Now, $R_1 = \rho\, l_1/A_1$ and $R_2 = \rho l_2/A_2$

$\therefore \quad \frac{R_2}{R_1} = \frac{l_2}{l_1}\frac{A_1}{A_2} = 3 \times 3 = 9$

$\therefore \; R_2 = 9 \times R_1 = 9 \times 10\ \Omega = \mathbf{90\ \Omega}.$

Example 8. *A dry cell of emf 1.6 V, and internal resistance of 0.10 Ω, is connected across a resistor of resistance R ohm. If the current drawn from the cell is 2 A, what is the*

(i) Voltage drop across R (ii) Energy dissipation in the resistor? **(CBSE 1993)**

Solution : We have $I = \frac{E}{R + r}$

$\therefore \; 2 = 1.6/(R + 0.10) \Rightarrow R + 0.10 = 1.6/2\ \Omega = 0.8\ \Omega \Rightarrow R = (0.8 - 0.1)\ \Omega = \mathbf{0.7\ \Omega}$

(*i*) The voltage drop across $R = IR = 2 \times 0.7 V = \mathbf{1.4\ V}$

(*ii*) The energy dissipated in $R = I^2 R = (2)^2 \times 0.7\ J = \mathbf{2.8\ J}.$

Example 9. *Three identical cells, each of emf 2 V and internal resistance 0.2 Ω are connected in series to an external resistor of 7.4 Ω. Calculate the current in the circuit.* **(CBSE 1993)**

Solution. The total emf of the three cells connected in series = $(2 + 2 + 2)$ V = 6 V

Total internal resistance = $(0.2 \times 3)\ \Omega = 0.6\ \Omega$

External resistance used = $7.4\ \Omega$

$\therefore$ Total resistance of the circuit = $(7.4 + 0.6)\ \Omega = 8.0\ \Omega$

$\therefore \quad I = \frac{V}{R} = \frac{6}{8} A = \mathbf{0.75\ A}.$

Example 10. *A silver wire has a resistance of 2.1 Ω at 27 °C and a resistance of 2.7 Ω at 100 °C. Determine the temperature coefficient of resistance of silver.*

Solution : We know that

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$$R_2 = R_1 [(1 + \alpha)(t_2 - t_1)]$$

$$\Rightarrow \quad \alpha = \frac{(R_2 - R_1)}{R_1 (t_2 - t_1)} = \frac{(2.7 - 2.1)}{2.1\,(100 - 27)} = \frac{0.6}{2.1 \times 73} / ^\circ C = \mathbf{3.9 \times 10^{-3} / ^\circ C.}$$

Example 11. *A heating element, using nichrome, connected to a 230 V supply, draws an initial current of 3.2 A which settles after a few second to a steady value of 2.8 A. What is the steady temperature of the heating element, if the room temperature is 27.0°C? Temperature coefficient of resistnace of nichrome, averaged over the temperature range involved, is* $1.70 \times 10^{-4} / ^\circ C$.

Solution : We have R_1 = initial resistance (at 27 °C) = $\frac{230}{3.2} \Omega = 71.87 \Omega$

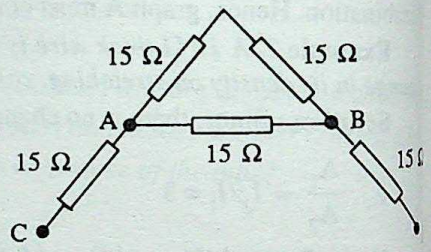
R_2 = final resistance (at t °C, say) = $\frac{230}{2.8} \Omega = 82.14 \Omega$

Now, $R_2 = R_1 [1 + \alpha (t - 27)]$

$\therefore \; 1 + \alpha (t - 27) = R_2 / R_1 = \frac{82.14}{71.87} = 1.141$

$\therefore (t - 27) = (1.141 - 1)/\alpha = \frac{0.141}{1.70 \times 10^{-4}} ^\circ C \approx 830 ^\circ C \Rightarrow t = (830 + 27) ^\circ C = \mathbf{857 ^\circ C.}$

Example 12. *Five resistances of 15 Ω each are connected in the way shown. What is the equivalent resistance between (i) the points A and B and (ii) between the points C and D of this combination?*

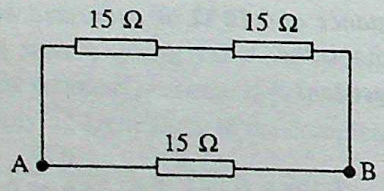


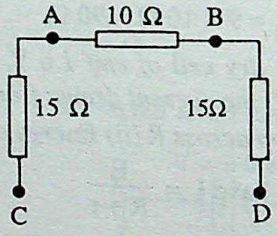
Solution : We can easily find the equivalent resistance between points A and B redrawing the given arrangement in the manner shown in (a) below.

(i) It is now clear that the equivalent resistance between A and B is given by

$$\frac{1}{R_{AB}} = \frac{1}{30} + \frac{1}{15} = \frac{3}{30} = \frac{1}{10}$$

$$\therefore \quad R_{AB} = 10 \Omega$$

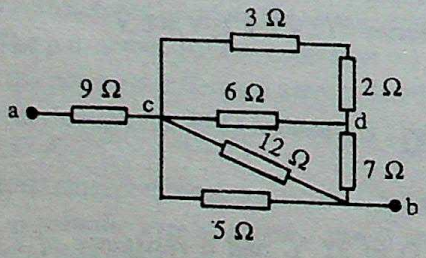


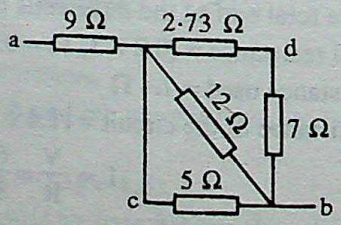


To get the equivalent resistance between points C and D, we can now redraw the given arrangement as shown in Fig. (b).

We, thus, have $R_{CO} = (15 + 10 + 15) \Omega = \mathbf{40 \Omega.}$

Example 13. *Find the equivalent resistance between points a and b for the combinations shown in Fig. below.*





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Solution : The 3 Ω and 2 Ω resistors are in series and are equivalent to a 5 Ω resistor. The equivalent 5 Ω is n parallel with the 6 Ω and their equivalent R′ is given by

$$\frac{1}{R'} = \frac{1}{5} + \frac{1}{6} = 0.20 + 0.16 = 0.367\ \Omega$$

$$\therefore \quad R' = \frac{1}{0.367} = 2.73\ \Omega$$

The given circuit, thus, far reduced is shown in adjoining figure.

The 7 Ω and 2.73 Ω resistors are equivalent to 9.73 Ω as they are in series. Now, the 5 Ω, 12 Ω and 9.73 Ω esistances are in parallel. Let their equivalent be R″. Then

$$\frac{1}{R''} = \frac{1}{5} + \frac{1}{12} + \frac{1}{9.73} = 0.386\ \Omega$$

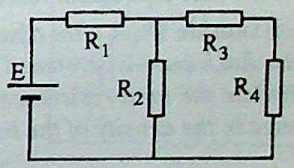
$$\therefore \quad R'' = \frac{1}{0.386} = 2.6\ \Omega$$

This 2.6 Ω is in series with the 9 Ω resistor. Therefore, the equivalent resistance of the combination is 9 + 2.6 = **11.6 Ω.**

Example 14. *Determine the voltage drop across the resistor R_1 in the circuit given below with* $E = 6.5$ V, $R_1 = 50\ \Omega$, $R_2 = 100\ \Omega$ $R_3 = 100\ \Omega$ and $R_4 = 300\ \Omega$ **(CBSE 1994)**

Solution : The equivalent resistance of R_3 and R_4 in series is $(100 + 300)\ \Omega = 400\ \Omega$.

This resistance of 400 Ω is in parallel across R_2 (= 100 Ω). Hence, the equivalent resistance, r of the combination is given by



$$\frac{1}{r} = \frac{1}{100} + \frac{1}{400} = \frac{4+1}{400} = \frac{5}{400}$$

Hence, $r = 80\ \Omega$

The (equivalent) resistance of 80 Ω is in series with R_1 (= 50 Ω).

Hence, the total resistance, R, of the circuit is $R = (50 + 80)\ \Omega = 130\ \Omega$

$\therefore$ Current drawn from the battery, $I = \frac{65\ \text{V}}{130\ \Omega} = 0.5\ \text{A}$

The voltage drop across R_1 (= 50 Ω) due to the flow of this current (= 0.5 A) through it,

$V = IR_1 = 0.5 \times 50\ \text{V} = \mathbf{25\ V}$

Example 15. *A student obtains resistances of 3, 4, 12 and 16 ohms using only two metallic resistance wires either separately or joined together. What is the value of resistance of each of these wires?* **(CBSE 1997)**

Solution : The resistance wires are of 4 Ω and 12 Ω. Joining these two in series, the equivalent resistance in (4+12) Ω = 16 Ω. Joining these two in parallel, the equivalent resistance is $\frac{4 \times 12}{4 + 12}\ \Omega = 3\ \Omega$.

Example 16. *Two wires A and B are of the same metal, have the same area of cross-section and have their lengths in the ratio 2 : 1. What will be the ratio of currents flowing through them respectively, when the same potential difference is applied across length of each of them.* **(CBSE 1998)**

Solution : We know that $R = \rho \frac{l}{A}$.

Here, ρ and A are same for both the wires and length of the wires are in the ratio of 2 : 1. Therefore, resistances of the two wires are in the ratio of 2 : 1 i.e., $R_A : R_B = 2 : 1$

Now, $I = \frac{V}{R} \Rightarrow I_A = \frac{V}{R_A}$ and $I_B = \frac{V}{R_B} \Rightarrow \frac{I_A}{I_B} = \frac{R_B}{R_A} = 1 : 2$

So, the ratio of currents in the two wires is 1 : 2.

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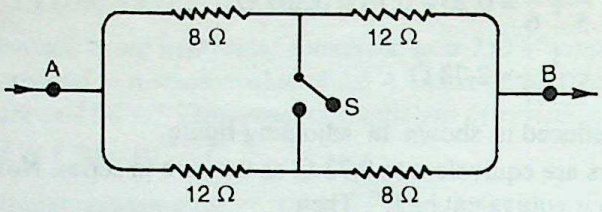
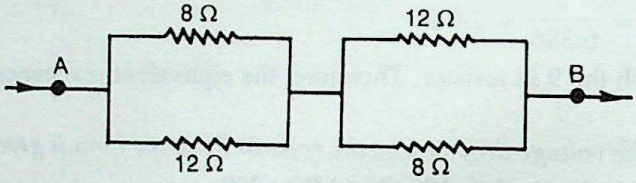
Example 17. *Calculate the equivalent resistance of the resistance network between the points A and B shown in the figure, when switch S is closed.*



(CBSE 199

Solution : On closing the switch S, the circuit becomes as shown below.



The equivalent resistance of 8 Ω and 12 Ω resistances in parallel is $\frac{12 \times 8}{12 + 8} = 4.8\ \Omega$

Now, the equivalent resistance of 4.8 Ω and 4.8 Ω resistances in series is (4.8 + 4.8) Ω = **9.6 Ω.**

Example 18. *A wire of uniform cross-section and length l has a resistance of 16 Ω. It is cut into four equ parts. Each part is stretened uniformly to length l and all the four stretened parts are connected in parall Calculate the total resistance of the combination so formed. Assume that stretching of wire does not cause a change in the density of the material.*

(CBSE 199

Solution : We know that $R = \rho \frac{l}{A}$

The wire of length l and resistance 16 Ω is cut into 4 equal parts, the length of each part will be $\frac{l}{4}$. Therefore, the resistance of each part will be 4 Ω.

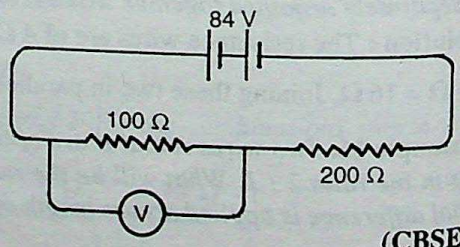
Now, each part is stretched uniformly to length l (4 times of its length), the area of cross-section becom $\frac{1}{4}$th. Therefore, resistance of each part will become. (16 × 4) Ω = 64 Ω.

Now, the equivalent resistance of four 64 Ω resistances in parallel is $\frac{64}{4}\ \Omega = 16\ \Omega$.

Example 19. *A voltmeter V of resistance 400 Ω is used to measure the potential difference across a 100 Ω resistor in the circuit shown below.*

(i) What will be reading on the voltmeter?

(ii) Calculate the p.d. across 100 Ω resistor before the voltmeter is connected.



(CBSE 199

Solution : 100 Ω resistance and voltmeter resistance of 400 Ω is equivalent to $\frac{400}{4+1}\ \Omega = 80\ \Omega$. This 80 Ω resistance and 200 Ω resistance give equivalent resistance of the circuit which is equal to (80 + 200) Ω = 280 Ω

$\therefore$ Current in the circuit $= \frac{84}{280}\ A = \frac{3}{10}\ A$

(i) $\therefore$ Voltmeter reading $= \frac{3}{10} \times 80\ V = \mathbf{24\ V.}$

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(ii) Before the voltmeter is connected in the circuit, the total resistance of the circuit is 300. Therefore, total current will be $\frac{84}{300}$ A.

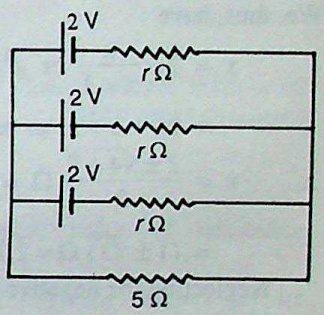
$\therefore$ P.d. cross the 100 Ω resistor = $\frac{84}{300} \times 100$ V = **28 V.**

Example 20. *A wire of resistance of 4R is cut into four equal parts. Each part is stretched to twice of its original length. If all the four wires after stretching are connected in parallel, calculate the resistance of the combination.* **(CBSE 1999)**

Solution: Proceed as in example 18.

Example 21. *Three identical cells each of emf 2V and unknown internal resistance are connected in parallel. The combination is connected to a 5 Ω resistor. If the terminal voltage across the cells is 1.5 V, what is the terminal resistance of each cell?* **(CBSE 1999)**

Solution : The following figure shows the arrangement. The combination of cells is equivalent to a single cell of emf 2 V and internal resistance $\frac{r}{3}$ Ω. If I be the current in the 5 Ω resistor, then $I = \frac{2}{5 + \frac{r}{3}}$



Now, $V = IR = \left(\frac{2}{5 + \frac{r}{3}}\right)$ (5)

Here, V = potential difference across R = terminal voltage of each cell = 1.5 V.

$= \left[\frac{2}{\left(5 + \frac{r}{3}\right)}\right]$ (5)

$\Rightarrow 0.3 = \frac{6}{15 + r} \Rightarrow 15 + r = \frac{6}{0.3} = 20 \Rightarrow r = 20 - 15 = \mathbf{5\ \Omega.}$

Example 22. *Two wires of equal length, one of aluminium and the other of copper have the same resistance. Which of the two wires is lighter? Hence, explain why aluminium wires are preferred for overhead power cables.*

($\rho_{Al} = 2.63 \times 10^{-8}$ Ω m, $\rho_{Cu} = 1.72 \times 10^{-8}$ Ω m, relative density of Al = 2.7, of Cu = 8.9).

Solution : We know that $R = \rho \frac{l}{A}$

Writing $\frac{l}{A}$ as $\frac{l^2}{Al} = \frac{l^2}{V} = \frac{l^2 d}{Vd} = \frac{l^2 d}{m}$ (d = density, V = volume, m = mass), we have

$$R = \frac{\rho\, l^2\, d}{m}$$

Using subscripts 1 and 2 for aluminium and copper respectively, we have

$$R_1 = \frac{\rho_1 l_1^2 d_1}{m_1} \text{ and } R_2 = \frac{\rho_2 l_2^2 d_2}{m_2}$$

We are given that $R_1 = R_2$ and $l_1 = l_2$. Hence,

$$\frac{\rho_1 d_1}{m_1} = \frac{\rho_2 d_2}{m_2} \text{ or } \frac{m_1}{m_2} = \frac{\rho_1 d_1}{\rho_2 d_2}$$

Substituting values, we get

$$\frac{m_1}{m_2} = \frac{2.63 \times 10^{-8}}{1.72 \times 10^{-8}} \times \frac{2.7}{8.9} = \frac{2.63 \times 2.7}{1.72 \times 8.9} = \mathbf{0.464.}$$

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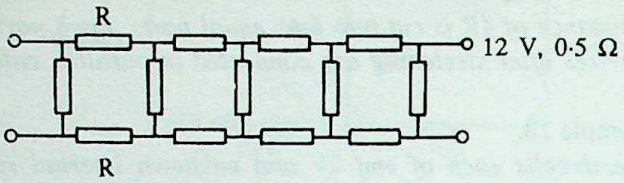
Thus, $m_1 < m_2$ or the aluminium wire is lighter than the copper wire. The lightness of aluminium wire needed, thus, makes them preferable for overhead power cables.

Example 23. *Determine the current drawn from a 12 V supply with internal resistance 0.5 Ω by the following infinite network. Each resistor has 1 Ω resistance.*



Solution : We notice that since the network is infinite one, addition of one more of its 'constituent units' should not change its equivalent resistance. We, therefore, say that the equivalent resistance of the combination shown in above fig. is also x ohm. Now equivalent resistance of the combination shown in fig. below.

$$\left[1+\frac{1}{\frac{1}{1}+\frac{1}{x}}+1\right]\Omega=\left[1+\frac{x}{x+1}+1\right]\Omega=\left(2+\frac{x}{x+1}\right)\Omega$$

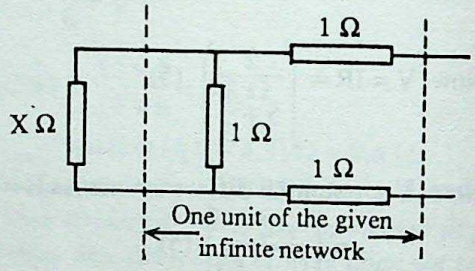
We, thus, have

$$x = 2+\frac{x}{x+1} \quad \text{or} \quad x^2+x$$

$$= 2x+2+x \quad \text{or} \quad x^2-2x-2=0$$

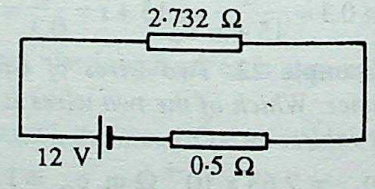
$$\therefore \quad x = \frac{2\pm\sqrt{4+8}}{2}\Omega = \left(\frac{2\pm\sqrt{12}}{2}\right)\Omega$$

$$= (1\pm\sqrt{3})\,\Omega = 2.732\,\Omega \text{ or } -0.732\,\Omega$$



Neglecting the negative value, we have $x = 2.732\,\Omega$

The equivalent resistance of the given network is, thus, 2.732 Ω.
The given circuit can, thus, be represented by the adjoining fig.



Clearly, the current drawn from the cell is $I = \frac{12\text{ V}}{(2.732+0.5)}\Omega$

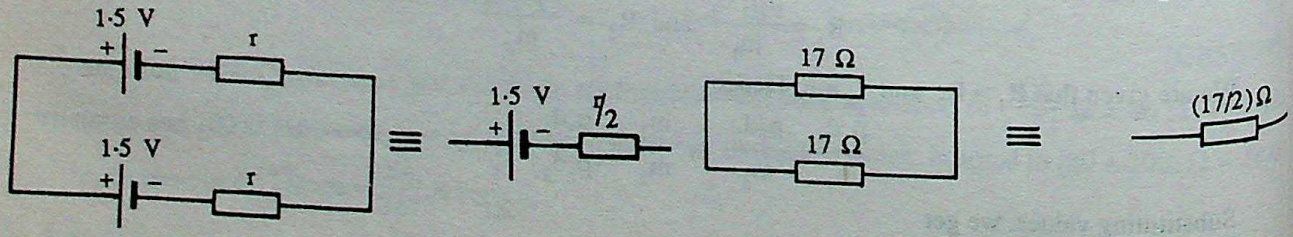
$$= \frac{12}{3.232}\text{ A} \approx \mathbf{3.71\ A.}$$

Example 24. *Two identical cells of emf 1.5 V each joined in parallel, provide supply to an external circuit consisting of two resistances of 17 Ω each joined in parallel. A very high resistance voltmeter reads the terminal voltage of the cells to be 1.4 V. Calculate the internal resistance of each cell.*

(CBSE 1995 Comptt.)

Solution : Let r be the internal resistance of each cell. The combination of the two cells in parallel, is then equivalent to a single cell of emf 1.5 V and internal resistance (r/2) ohm.

The two resistances of 17 Ω each, connected in parallel, are equivalent to a single resistance of $\frac{17}{2}\Omega$.



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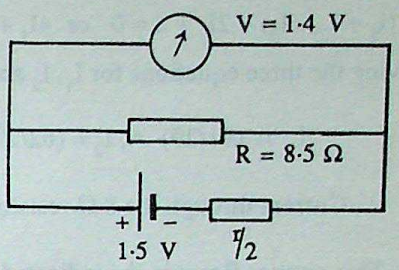
The required equivalent circuit is, therefore, as above. The reading of the high resistance voltmeter is 1.4 V. Also the current drawn from equivalent cell is

$$I = \left(\frac{1.5}{8.5 + r/2}\right) \quad \therefore \quad \frac{1.5}{(8.5 + r/2)} \times (8.5) = 1.4$$

$$\Rightarrow \quad \left(8.5 + \frac{r}{2}\right) = \frac{1.5 \times 8.5}{1.4}\ \Omega$$

$$\Rightarrow \quad \frac{r}{2} = \left(\frac{1.5}{1.4} - 1\right) \times 8.5\,\Omega = \frac{0.1 \times 8.5}{1.4}\ \Omega$$

$$\Rightarrow \quad r = \frac{1.7}{1.4}\ \Omega = \mathbf{1.21\ \Omega}.$$



Example 25. *The sequence of bands marked on a carbon resistor are yellow, red, orange and silver. What is its (i) resistance (ii) tolerance ?* **(CBSE 1993)**

Solution : We have yellow = 4; red = 2; orange = 3

$\therefore$ Value of resistance = $42 \times 10^3\ \Omega = \mathbf{42\ k\Omega}$.

Also the silver band implies a tolerance of 10 %. Hence, tolerance = 10 %

Example 26. *On a given resistor, the colour bands are in the sequence ; green, violet and red. What is its resistance?* **(CBSE 1993 Comptt.)**

Solution : We have, green 5; violet = 7; red = 2

Hence, value of resistance = $57 \times 10^2\ \Omega = \mathbf{5.7\ k\Omega}$

Since, there is no fourth (colour) band, the tolerance is 20 %. Hence, value of resistance = $\mathbf{(5.7 \pm 20\ \%)\ k\Omega}$.

Example 27. *A Carbon resistor of 47 kΩ is to be marked with rings of different colours for its identification. Write the sequence of colours.* **(CBSE 1994)**

Solution : The given resistor is $47 \times 10^3\ \Omega$

We have, yellow = 4; violet = 7; orange = 3

The required sequence of colours is **yellow, violet, orange**.

Example 28. *A carbon resistor of 74 kΩ is to be marked with rings of different colours for its identification. Write the sequence of colours.* **(CBSE 1994)**

Solution : The given resistor is $74 \times 10^3\ \Omega$

We have 7 = violet, 4 = yellow, 3 = orange.

Hence, the required sequence of colours is **violet, yellow, orange.**

Example 29. *A voltage of 30 V is applied across a colour coded carbon resistor with first, second and third rings of blue, black and yellow colours. What is the current flowing through the resistor?* **(CBSE 1994 Comptt.)**

Solution : We have : blue = 6; black = 0; yellow = 4

$\therefore$ Value of the resistor = $60 \times 10^3\ \Omega$

Voltage applied = 30 V

$\therefore$ Current flowing = $\dfrac{30\text{V}}{60 \times 10^3\ \Omega} = 0.5 \times 10^{-3}\ \text{A} = \mathbf{0.5\ mA}$.

Example 30. *For the network shown in fig. below find the current through the 8 Ω resistor.*

Solution : Let the currents 'flowing out' from the three batteries be denoted by I_1, I_2, I_3 shown. Applying Kirchoff's second law to the mesh KMNLK we get

$-8 + 2I_2 - 4I_1 + 10 = 0$ or $2I_1 - I_2 = 1$

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For the mesh MOPNM, we have

$6 - 3I_3 - 2I_2 + 8 = 0$ or $2I_2 + 3I_3 = 14$

For the mesh NABNM, we have

$-8(I_1 + I_2 - I_3) - 2I_2 + 8 = 0$ or $4I_1 + 5I_2 - 4I_3 = 4$

Solving the three equations for I_1, I_2 and I_3, we get

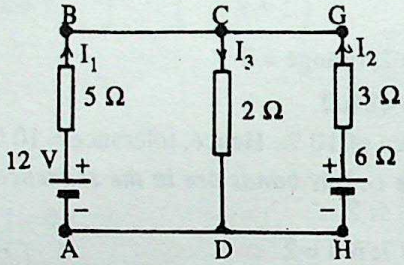
$$I_1 = (91/29)\ \text{A}, I_2 = (62/29)\ \text{A}, I_3 \frac{279}{58}\ \text{A}$$

$\therefore$ Current through the 8 Ω resistor $= I_1 + I_2 - I_3 = \left(\frac{182}{58} + \frac{124}{58} - \frac{279}{58}\right)\text{A} =$ **27/58 A.**

This current flows in the indicated direction.

Example 31. *Using Kirchoff's laws in the given electrical network, calculate the values of I_1, I_2 and I_3*

(CBSE 199



Solution : Applying Kirchoff's first law at the point C, we have $I_1 - I_3 + I_2 = 0$ or $I_3 = I_1 + I_2$

Using the second law for the mesh ABCDA, we have $12 - 5I_1 - 2I_3 = 0$ or $12 - 5I_1 - 2(I_1 + I_2) = 0$

or $7I_1 + 2I_2 = 12$

Again, applying the second law of the mesh ABCGHDA, we have $12 - 5I_1 + 3I_2 - 6 = 0$

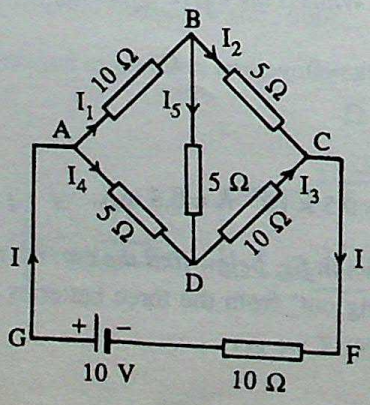
or $5I_1 - 3I_2 = 6$

Solving the two equations for I_1 and I_2, we get $I_1 = (48/31)$ A, $I_2 = (18/31)$ A

$\therefore$ $$I_3 = \left(\frac{48 + 18}{31}\right)\text{A} = \frac{66}{31}\text{A}$$

Hence, we have $$\mathbf{I_1 = \frac{48}{31}\ A,\ I_2 = \frac{18}{31}\ A,\ I_3 = \frac{66}{31}A.}$$

Example 32. *Determine the current in each branch of the netwrok shown in fig. below.*



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Solution : Let the various unknown currents be indicated as shown. We then have, from Kirchoff's first law:

$I = I_1 + I_4$ (Point A);

$I = I_2 + I_3$ (Point C)

$I_1 = I_2 + I_5$ (Point C).

We may then write

$$I_4 = (I - I_1),\ I_3 = (I - I_2) \text{ and } I_5 = (I_1 - I_2)$$

Now applying Kirchoff's second law to

(*i*) loop ABDA : $-10I_1 - 5I_5 + 5I_4 = 0$

or $\quad -10I_1 - 5(I_1 - I_2) + 5(I - I_1) = 0$

or $\quad 5I - 20I_1 + 5I_2 = 0$

or $\quad I - 4I_1 + I_2 = 0$

(*ii*) loop BCDB : $-5I_2 + 10I_3 + 5I_5 = 0$

or $\quad -5I_2 + 10(I - I_2) + 5(I_1 - I_2) = 0$

or $\quad 2I + I_1 - 4I_2 = 0$

(*iii*) loop ABCEGA $-10I_1 - 5I_2 - 10I + 10 = 0$

or $\quad 2I + 2I_1 + I_2 = 2$

Solving the three equations for I, I_1 and I_2, we get

$$I = (10/17)\text{ A},\ I_1 = 4/17\text{A},\ I_2 = (6/17)\text{ A}$$

$$\therefore\quad I_3 = I - I_2 = (10/17 - 6/17)\text{ A} = (4/17)\text{ A}$$

$$I_4 = I - I_1 = (10/17 - 4/17)\text{ A} = (6/17)\text{ A}$$

and $\quad I_5 = I_1 - I_2 = \frac{4}{17} - \frac{6}{17} = -(2/17)\text{ A}$

The negative sign with I_5 implies that the current in the arm BD is actually flowing from D to B.

Example 33. *The four arms of a Wheatstone bridge are as under, arm AB a resistance of 5 Ω, arm BC a resistance of 10 Ω arm CD a resistance of 15 Ω and arm DA a resistance of 20 Ω. A battery with an emf of 2 V and internal resistance 0.5 Ω is connected across A and C, galvanometer having a resistance of 20 Ω is connected across B and D. Find the current flowing in the galvanometer.*

Solution. The distribution of current in the various arms of the Wheatstone bridge is shown in Fig. below in accordance with Kirchoff's first law.

Applying Kirchoff's 2nd law to the loop ABDA, we get

$$5i_1 + 20i_g - 20(i - i_1) = 0$$

or $\quad 25i_1 + 20i_g - 20i = 0 \qquad ...(i)$

Similarly, for the loop BCDB, we have

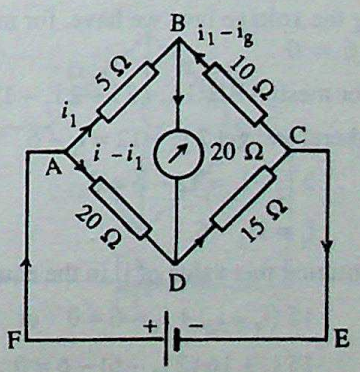
$$10(i_1 - i_g) - 15(i - i_1 + i_g) - 20i_g = 0$$

or $\quad 25i_1 - 45i_g - 15i = 0 \qquad ..(ii)$

For the loop ABCDEFA we get

$$5i_1 + 10(i_1 - i_g) + 0.5i = 2$$

or $\quad 15i_1 - 10i_g + 0.5i = 2 \qquad ...(iii)$



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Substracting Eqn. (*ii*) from Eqn. (*i*), we get $65i_g - 5i = 0$

or $\quad i = 13i_g \quad ...(iv)$

Multiplying Eqn. (*i*) by 3 and Eqn. (*ii*) by 5 and subtracing, we get

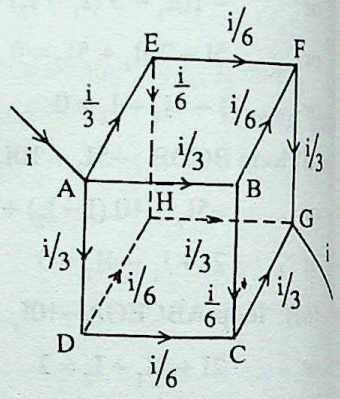
$$110i_g - 62{\cdot}5i = -10$$

$$\Rightarrow 110\, i_g - 62.5 \times 13i_g = -10$$

$$\Rightarrow \quad i_g = \frac{10 \times 2}{1405} = \mathbf{0.0142\ A.}$$

Example 34. *Twelve equal wires, each of resistance r are joined up to form a skeleton cube. A curre enters at one corner and leaves at the diagonally opposite corner. What resistance does the cube offer in th situation?*

Solution : Let ABCDEFGH be a skeleton cube formed by 12 wires each of resistance r Ω. Let the current entering at A be i and let it leave at the diagonally opposite corner G. Since the resistance of each wire is the same, the main current i is divided at A into three equal parts, *i.e.*, i/3 along AE, AB and AD respectively.



At the points, B, D and E, this current i/3 is further divided into two equal parts, each of magnitude i/6.

At the points, C, F and H, the currents again combine to give currents, each of magnitude i/3 along CD, FG and HG respectively. At G these currents combine and so the current leaving at G is i.

Let R be the equivalent resistance between the corners A and G. Then taking any one of the paths between A and G, say ABCG, (fig. above) we have

p.d. between A and G = p.d. between A and B + p.d. between B and C + p.d. between C and G

$$\therefore iR = \frac{ir}{3} + \frac{ir}{6} + \frac{ir}{3}$$

$$\therefore R = \frac{\mathbf{5r}}{\mathbf{6}}.$$

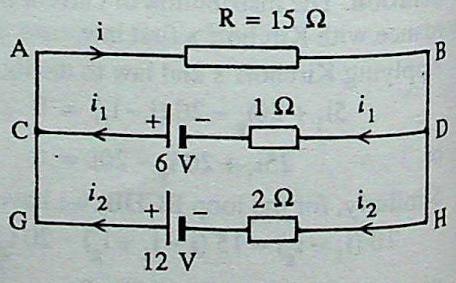
Example 35. *Two cells of emf 6 V and 12 V, and internal resistances 1 Ω and 2 Ω respectively, a connected in parallel so as to send current in the same direction through an external resistance of 15 Ω.*

(i) Draw the circuit diagram.

(ii) Using Kirchoff's laws, calculate the (a) current through each branch of the circuit and (b) the p across the 15 Ω resistance.

(CBSE 199

Solution : (*i*) The required circuit diagram is shown.



(*ii*) We have, by current law, $i = i_1 + i_2$

Using the voltage law, we have, for mesh ABDCA

$15i + i_1 - 6 = 0$

and for mesh ABHGA, $15\, i + 2\, i_2 - 12 = 0$

We, therefore, get $2\, i_2 - 12 = i_1 - 6$

or $\quad 2\, i_2 - i_1 = 12 - 6 = 6$

$\therefore \quad i_1 = 2i_2 - 6$

Substituting this value of i_1 in the equation $15i + i_1 - 6 = 0$

$15\,(i_1 + i_2) + i_1 - 6 = 0$ or $15\, i_2 + 16\, i_1 - 6 = 0$, we get

$15\, i_2 + 16\,(2\, i_2 - 6) - 6 = 0$

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$\therefore \quad 47\, i_2 + 102 \quad \text{or} \quad i_2 = \dfrac{102}{47}$ **A**

$\therefore \quad i_1 = \dfrac{2 \times 102}{47} - 6 = \dfrac{204}{47} - 6 = \dfrac{204 - 282}{47} = -\dfrac{78}{47}$ **A**

$\therefore \quad i = i_1 + i_2 = -\dfrac{78}{47} + \dfrac{102}{47} = \dfrac{24}{47}$ **A**

$\therefore$ p.d. across R (= 15 Ω) $= \dfrac{24}{47} \times 15$ V $= \dfrac{360}{47}$ **V** .

The negative sign with i_1 implies that the current in the arm CD is really opposite to the direction shown.

Example 36. *In the following diagram* P = 3 Ω, Q = 2 Ω, R = 6 Ω, S = 4 Ω, X = 5 Ω *Calculate the current I. (Ignore internal resistance of the cell)* **(CBSE 1992)**

Solution : The given wheatstone bridge is a balanced one as $\dfrac{P}{Q} = 3/2$ and R/S = 6/4 = 3/2

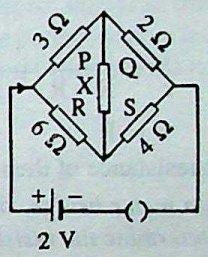
$\therefore \quad \dfrac{P}{Q} = \dfrac{R}{S}$

Hence, the equivalent resistance r, of the network is

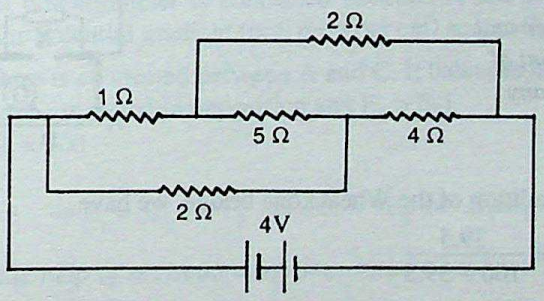
$$\frac{1}{r} = \frac{1}{3+2} + \frac{1}{6+4} = \frac{1}{5} + \frac{1}{10} = \frac{3}{10}$$

$\therefore \quad r = \left(\dfrac{10}{3}\right)\Omega$

$\therefore$ Current $I = 2/r = \dfrac{2 \times 3}{10}$ A = **0.6 A.**



Example 37. *Calculate the current drawn from the battery in the following network.*



(CBSE 1997)

Solution : The given circuit is equivalent to Wheatstone bridge.

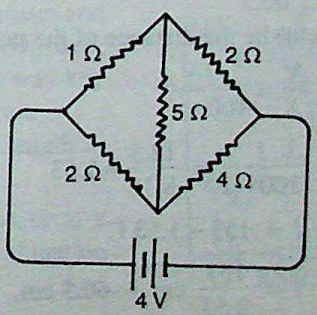
As $\dfrac{1\ \Omega}{2\ \Omega} = \dfrac{2\ \Omega}{4\ \Omega}$

When bridge is balanced, the 5 Ω resistance is not effective.

We have (1 + 2) Ω and (2 + 4) Ω resistances in parallel.

$\therefore$ Equivalent resistance is given by $\dfrac{6}{2+1}\ \Omega = 2\ \Omega$

$\therefore$ Current, $I = \dfrac{4\ V}{2\ \Omega} =$ **2A.**



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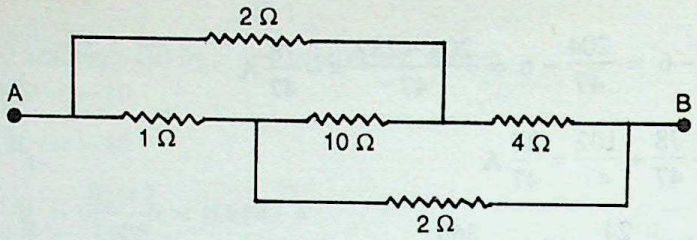
Example 38. *Calculate the equivalent resistance between A and B in the following figure.*



(CBSE 1999)

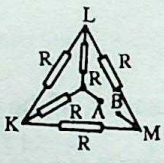
Solution: Proceed as in example 37.

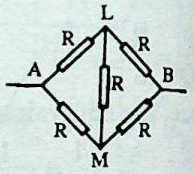
Answer **2 Ω**.

Example 39. *If each of the resistances in the network shown is R, what is the effective resistance between the terminals A and B.*

Solution : A careful look at the network shown reveals that it is nothing but a *balanced Wheatstone bridge*. This is shown fig below.

We can, therefore, neglect the resistance R between M and L. The equivalent resistance of the remaining four resistances is given by





$$\frac{1}{r} = \frac{1}{R+R} + \frac{1}{R+R} = \frac{2}{2R} = \frac{1}{R}$$

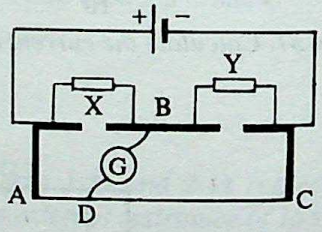
$$\therefore \quad r = R$$

Thus, the equivalent resistance of the network between A and B is again R.

Example 40. *(a) In a meter bridge, the balance point is found to be at 39.5 cm from the end A, when the resistor Y is of 12.5 Ω. Determine the resistance of X.*

(b) Determine the balance point of the bridge above if X and Y are interchanged.

(c) What happens, if the galvnometer and cell are interchanged at the balance point of the bridge? Would galvanometer show any current?



Solution : (a) From the balance condition of the Wheatstone bridge, we have

$$\frac{X}{Y} = \frac{\text{Resistance of AD}}{\text{Resistance of DC}} = \frac{39.5}{100 - 39.5}$$

$$X = \frac{39.5}{60.5} \times 12.5\ \Omega = \mathbf{8.16\ \Omega}.$$

(*b*) Let l (in cm) be the distance of the point D from end A when X and Y are interchanged. We then have

$$\frac{Y}{X} = \frac{l}{100 - l}$$

or $$\frac{l}{100 - l} = \frac{12.5}{8.16} = 1.53$$

or $$l = 153 - 1.53\, l$$

$$\therefore \quad l = \frac{153}{2.53}\ \text{cm} \approx \mathbf{60.5\ cm}.$$

(*c*) When the galvanometer and cell are interchanged at the balanced point, there is no change in the balance point. Hence, the galvanometer will show zero current after such an interchange.

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Example 41. *A potentiometer wire has a length of 10 m and resistance 4 Ω/m. An accumulator of emf 2V and a resistance box are connected in series with it. Calculate the resistance to be introduced in the box so as to get a potential gradient of (i) 0.1 V/m, and (ii) 0.001 mV/m.*

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Solution. Let R indicate the resistance introduced from box and L_ρ the resistance of the potentiometer wire.

Then $I = \dfrac{E}{R + L_\rho}$

When ρ is the resistance per unit length of wire. Then

potential gradient = $I_\rho = \dfrac{E\rho}{R + L_\rho}$

(i) We are given

$E = 2V$, $L = 10$ m, $\rho = 4$ Ω/m and pot. gradient = 0.1 V/m

$\therefore\ 0.1 = \dfrac{2}{(R + 10 \times 4)} \times 4$

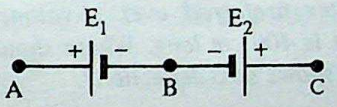
or $0.1R + 4 = 8 \quad \therefore\ \mathbf{R = 40\ \Omega}.$

(*ii*) Now pot. gradient = 10^{-3} V/m

$$10^{-3} = \frac{2}{(R + 40)} \times 4 \quad \therefore\ \mathbf{R = 7960\ \Omega}.$$

Example 42. *Two cells of emf E_1 and E_2 ($E_1 > E_2$) are connected as shown in the figure below. When a poteniometer is connected between A and B, the balancing length of the potentiometer is 300 cm. On connecting the same potentiometer between A and C, the balancing length is 100 cm. Calculate the ratio of E_1 and E_2.*

(CBSE 1994)



Solution : When the potentiometer is connected between A and B, it balances only the emf E_1. Hence, $E_1 = k \times 300$, where k is the potential gradient (pot. drop per cm) across the given potentiometer wire.

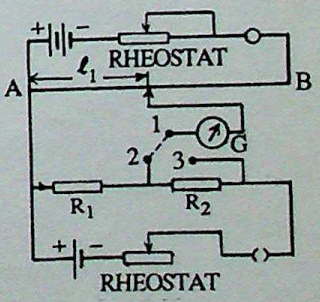
When the potentiometer is connected between A and C, it balances the difference (E_1 - E_2) of the two cells. (The two cells E_1 and E_2 are connected in opposition and $E_1 > E_2$).

Hence, $(E_1 - E_2) = k \times 100$

$$\therefore \frac{E_1}{E_1 - E_2} = \frac{300}{100} = 3 \quad \Rightarrow E_1 = 3E_1 - 3E_2 \quad \Rightarrow 2E_1 = 3E_2 \text{ or } \mathbf{E_1/E_2 = 3/2}.$$

Example 43. *With the help of a circuit diagram, explain how you would compare the resistances of two given resistors using a potentiometer.* **(CBSE 1993)**

Solution : The required circuit diagram is shown below.



Here AB is the potentiometer wire across which a battery, a rheostat and key are connected as shown. R_1 and R_2, the two resistances to be compared, are connected in series, across a cell and a rheostat as shown. A two way key and the galvanometer and jockey are connected to complete the circuit.

With points 1 and 2 connected, let the balance point occur at a length l_1. The length l_1, then balances the p.d. across R_1. Hence, $IR_1 = kl_1$

When point 1 and 3 are connected, let the balance point occur at a length l_2. The length l_2 then balances the p.d. across the series combination of R_1 and R_2

Hence, $I\ (R_1 + R_2) = k\ l_2$

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We thus, get, $\frac{R_1 + R_2}{R_1} = \frac{l_2}{l_1}$

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or $\frac{R_2}{R_1} = \frac{l_2}{l_1} - 1 = \left(\frac{l_2 - l_1}{l_1}\right)$

We can use this relation to compare the value of the two given resistors.

Example 44. *A potentiometer wire of length 100 cm has a resistance of 10 Ω. It is connected in series with a resistance and a cell of emf 2V and of negligible internal resistance. A source of emf 10 mV is balanced at a length of 40 cm of the potentiometer wire. What is the value of the external resistance.*

Solution : We have : 40 cm of potentiometer wire ≡ 10 mV source

$\therefore$ k = Potential drop per cm of the potentiometer wire = $\frac{10\text{ mV}}{40\text{ cm}} = 2.5 \times 10^{-4}$ V/cm

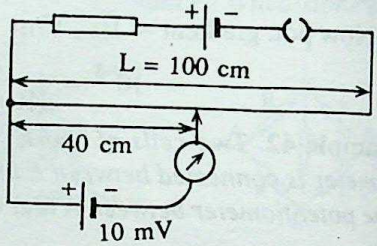
Now, $k = \frac{1}{L}\left(\frac{E}{R+r}\right)r$. This is so because the current in the potentiometer wire circuit is $I = \frac{E}{(R+r)}$, and hence, the p.d. across the whole length (L cm) of it is $Ir = rE/(R + r)$.

$\therefore \quad \frac{1}{100} \cdot \frac{2 \times 10}{R + 10} = 2.5 \times 10^{-4}$

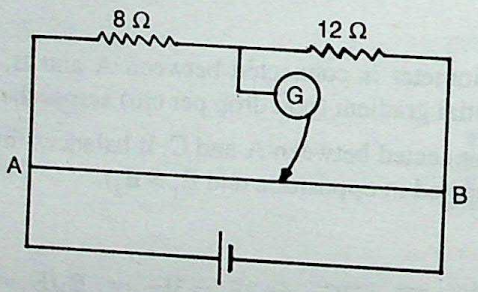
$$R + 10 = \frac{20\ \Omega}{100 \times 2.5 \times 10^{-4}}$$

or $R + 10 = \frac{2000}{2.5} = 800\ \Omega$

$\therefore \quad R = (800 - 10)\ \Omega = \mathbf{790\ \Omega}.$

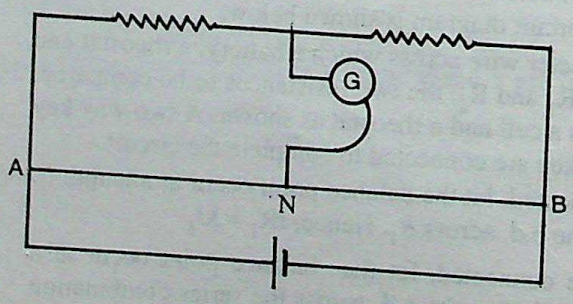


Example 45. *Why is a potentiometer preferred over a voltmeter to measure emf of a cell? The potentiometer wire AB shown in the figure is 400 cm long. Where should the free end of the galvanometer be connected on AB, so that the galvanometer shows zero deflection?* **(CBSE 1997**



Solution : See text for the first part. Let the free end of the galvanometer be connected at - N on AB, then

AN + NB = 400 ...(i)



Also, for zero deflection on the galvanometer

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$$\frac{AN}{NB} = \frac{8}{12} \Rightarrow NB = \frac{3AN}{2} \quad \text{...(ii)}$$

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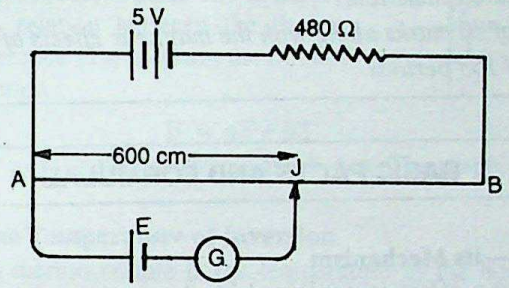
Putting the value of NB into (i), we have

$$AN + \frac{3AN}{2} = 400 \Rightarrow AN = \frac{2 \times 400}{5} = \mathbf{160}$$

Hence, the free end of the galvanometer should be connected at a distance of 160 cm from A on AB.

Example 46. *A 10 m long wire AB of uniform area of cross section and 20 Ω resistance is used as a potentiometer wire. This wire is connected in series with a battery or 5 V and a resistor of 480 Ω. An unknown emf is balanced at 600 cm of the wire as shown in the following figure. Calculate: (i) the potential gradient for the potentiometer wire. (ii) The value of unknown emf E.* **(CBSE 1998)**



Solution: (i) Total resistance of the circuit = (480 + 20) Ω = 500 Ω

$\therefore$ Current in the circuit $= \frac{5}{500}A = \frac{1}{100}A$

P.d. across the wire of resistance 20 Ω $= \frac{1}{100} \times 20 \text{ V} = \frac{1}{5} \text{ V} = 0.2 \text{ V}$

$\therefore$ Potential gradient along the wire of length 10 m $= \frac{V}{l} = \frac{0.2}{10} \text{ Vm}^{-1} = 0.02 \text{ Vm}^{-1}$

(ii) Since, potential gradient is 0.02 Vm^{-1},

$\therefore$ P.d. acros the 6 m wire = (0.02) × 6 V = 0.12 V.

Hence, the value of unknown emf E = **0.12 V.**

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UNIT – III

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THERMAL AND CHEMICAL EFFECTS OF CURRENTS

CBSE SYLLABUS CONTENTS

Electric power, heating effect of current , Joule's law. Chemical effect of current and Faraday's laws of electrolysis. Cell— primary (Voltaic, Leclanche, Daniell) and secondary (lead accumulator). Thermo electricity, Seebeck effect and its explanation.

Marks : 4 out of a total of 70 marks along with the magnetic effects of current.

Periods : 11 out of total of 168 periods

BASIC FACTS AND FORMULAE

The Heating effect of Currents— its Mechanism

The mechanism of the heating effect is explained by the motion of free electrons through metals. The electrons on their way collide frequently with atoms, in each collision the energy lost is conveyed to the atom with which the electron strike. Thus, kinetic energy of vibration of metal atoms is increased and as consequence heat is generated in the conductor.

Formulae for the Heating Effect

If a current of I ampere traverses a conductor between the ends of which there is a potential difference equ to V volt, the work done during a time t is VIt. If the whole energy liberated is converted into heat, the hea generated is given by $H = I^2Rt$

Joule's Law for the Heating Effect of Current

Joule's law is expressed by the above equation and according to the law, we say that the heat generated in simple circuit is proportional (i) to the square of the current, (ii) to the resistance and (iii) to the time during which the current flows.

Electrical Power

The electrical power is defined as the energy liberated per unit time in an electrical device. The power P can be expressed as

$$P = IV = I^2 R = \frac{V^2}{R}$$

The unit of power is watt.

The kilowatt-hour; its relation with the Joule

The unit used in practice, for estimating the consumption of electrical energy, is the *kilowatt hour.*

When a device of power one kilowatt, runs for one hour, it is said to consume one kilowatt hour (kWh) of electricity. Thus,

$1\ \text{kWh} = (1000\ \text{watt} \times 3600\ \text{s}) = 3.6 \times 10^5\ \text{W–s} = 3.6 \times 10^6\ \text{J}$

$\therefore\ 1\text{kWh} = 3.6\ \text{MJ}$

Thermo Electricity

Thermoelectricity is the study of the phenomenon involving the conversion of heat energy into electrical energy. The study consists of three related phenomena, namely :

(i) The Seebeck effect; (ii) The Peltier effect and (iii) The Thomson effect.

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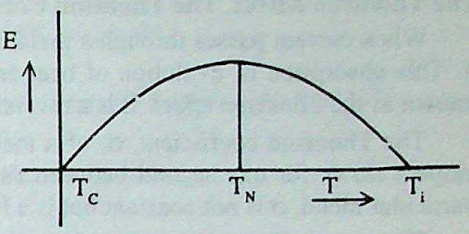
Seebeck Effect; The Thermo Couple

The flow of electric current in a closed circuit consisting of two dissimilar metals when the junctions are maintained at different temperatures, is known as the Seebeck *effect.* The e.m.f. responsible for the current flow is known as Seebeck e.m.f. The two metals forming the circuit are known as a *thermocouple.*

Variation of Thermo Emf with Temperature

It is found that the thermo *e.m.f.,* produced in a given thermocouple, varies in (almost) direct proportion to the difference of temperature between the hot and cold junctions, provided this difference is not too large. For larger values of the temperature difference, the variation becomes parabolic in nature. We, therefore, often express the relation between the thermo *e.m.f.* (E) and the temperature difference (T), between the hot and cold junctions by the quadratic relation :



$$E = aT + bT^2$$

Here a and b are constants for a given thermocouple and b <<a. The graph of the variation of E with T is of the form shown above.

The Neutral Temperature and the Temperature of Inversion

The neutral temperature of a thermo couple is the temperature of the hot junction at which the Seebeck e.m.f. is maximum. It is a constant of a particular thermocouple. Another useful parameter of a thermocouple is *the temperature of inversion.* It is that temperature of the hot junction at which e.m.f. is zero and is about to reverse. Temperature of inversion is not constant but depends on the temperature of the cold junction. It is always as much above the neutral temperature as the cold junction is below.

Thus, if T_N, T_C and T_i denote the neutral temperature, the cold junction temperature and the temperature of inversion respectively, for a given thermocouple, we have $T_N - T_C = T_i - T_N$ or $T_N = (T_C + T_i)/2$

The Free Electron Theory and the Seebeck Effect

The free electrons inside a metal can be considered to constitute an electron gas. The electron density is generally different in different metals. When two dissimilar metals are brought in contact, the electrons diffuse across the junction tending to equalise the electron density. The electron diffusion set up a junction potential difference. When the two junctions are at the same temperature the junction potential difference and, therefore, the e.m.f. at the two junctions are equal and opposite, the resultant e.m.f. is thus zero. When the junctions are at different temperatures the junction e.m.f's are different and there is a resultant e.m.f. acting around the circuit. This the Seebeck's e.m.f.

The Peltier Effect and the Peltier Coefficient

When an electric current is passed in a circuit of two dissimilar metals (*i.e.,* a thermocouple) heat is evolved at one junction and absorbed at the other. The effect is known as the *Peltier effect* and is the reverse of the Seebeck effect. The Peltier effect is reversible.

The amount of heat evolved or absorbed at a junction when unit current flows for one second is called the Peltier coefficient, π. Its units are joule/coulomb, *i.e.,* volt. The Peltier coefficient depends on the temperature and the materials of the junction.

Differences between the Peltier and the Joule Effects

- The Peltier effect is different from Joule effect in the following respects.

	Peltier Effect	*Joule Effect*
(i)	Heat is produced at a junction only.	Heat is produced all along the conductor.
(ii)	It is reversible.	It is irreversible.
(iii)	Heat generated is proportional to current.	Heat generated is proportional to the square of current.
(iv)	Heat is evolved at one junction and absorbed at the other.	Heat is always evolved.

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Understanding the Peltier Effect

This Peltier effect can be easily explained in terms of the junction potential. When an external curre passed through a thermocouple, energy is absorbed when the charge moves against the rise of the poten bringing about a fall of temperature. When charge moves along the junction potential the current does wo developing heat and thereby warming the junction.

The Thomson Effect, The Thomson Coefficient

When current passes through a metal having temperature distributed along it, heat is evolved or absorbe it. This absorption or evolution of heat energy due to the flow of current in an unequally heated conducto known as the *Thomson effect.* It is a reversible effect.

The Thomson coefficient, σ, of a metal is the energy absorbed or evolved in joule when a current of ampere flows for one second between two points of a conductor which differ in temperature by 1 K. Fo particular metal, σ is not constant but is a function of temperature.

Thomson effect can be roughly understood on the basis of the electron theory. In a metal hav temperature distribution, the electron diffusion takes place from the region of higher to lower temperature, t sets up a potential difference. When current flows through the metal, the charge moves along or against t potential difference resulting in the evolution or absorption of heat.

Uses of the Thermoelectric Effect

The thermoelectric effect can be used for the measurement of a wide range of temperatures. Temperatu measurements using thermocouples possess many distinct advantages over temperature measurements by ot methods. The thermoelectric effects has also been used in the development of *thermoelectric generators* a *refrigerators.* We also have devices like the thermopile, the thermal cross and the thermoelectric milliamme all of which are based on the thermoelectric effect.

Basic Definitions Concerning the Chemical Effects of Currents

An electrolyte is a conductor which undergoes chemical decomposition when transversed by a current electricity.

The terminals, or electrodes, by which the current enters and leaves the electrolyte are termed the anode a cathode respectively.

The elements, or group of elements, liberated at the electrodes are termed ions. The ion liberated at t anode is termed the anion and liberated at the cathode is termed the cation.

Arrhenius Theory of Electrolytic Dissociation

Arrhenius proposed that in a solution which forms a good electrolyte, most of the molecules dissociate in ions without the application of any electric field, In other words, there is almost complete electroly dissociation of the molecules of the solute. These ions are driven to the electrodes by the applied electric fie and, on arriving there either give up their charges and again assume the properties of uncharged atoms or ta part in secondary reactions.

The theory of dissociation neatly explains Faraday's laws of electrolysis. The concept of atomicity electricity is a direct consequence of Faraday's laws.

Faraday's First Law of Electrolysis

The mass of an ion set free by a current is proportional to the quantity of electricity which has passed. Thu if m be the mass of an ion deposited on the electrode, when a current I flows for a time t, we have

$$m \propto I t \text{ or } m = z I T$$

The constant, z, is known as the *electrochemical equivalent of the ion* concerned.

Faraday's Second Law of Electrolysis

If several different electrolytes are connected, in series in the same circuit, the relative masses of th liberated ions are proportional to their chemical equivalents.

Thus, $\frac{m_1}{m_2} = \frac{E_1}{E_2}$ where E_1 and E_2 are the equivalent weights of the two ions.

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The Electrochemical Equivalent (z)

The *electrochemical equivalent* of an element is that mass of it which is liberated by the passage of 1 coulomb of electricity.

It is interesting to note that the electrochemical equivalent (z), of any ion, is obtained by dividing its chemical equivalent weight (E) by the Faraday (F), where one faraday ≈ 96500 coulomb per gram mole. Thus, z = E/F.

Also E = A/p, where A = atomic weight and p = valency of the ion concerned.

The 'Faraday'

Charge required to deposit chemical equivalent of a substance in the same for all substances. This quantity of electricity has been named as the *faraday* (F).

It is easy to realize that the *faraday* would be the product of the electronic charge ($e = 1.6 \times 10^{-19}$ C) and the Avogadro's number, ($N_A \approx 6.023 \times 10^{23}$/g – mole). Thus ,

$$F = e\,N_A = 1.6 \times 10^{-19} \times 6.023 \times 10^{23} \text{coulomb/g-mole} \quad \text{or} \quad F \approx 96500 \text{ C/g–mole}$$

A Single Equation Combining the Two Laws of Electrolysis

Since m = z It and z = E/F, we have

$$m = \frac{E}{F} I t \quad \text{or} \quad m = \frac{A}{pF} I t, \ (\because E = A/p).$$

This equation, as is easy to see, can be regarded as a *single equation containing both of Faraday's laws of electrolysis.*

A summary of the Main Features of the Commonly used Cells and Accumulators

The following table gives the important features of commonly used cells :

Name of the cell	*Positive electrode rode*	*Negative electrode*	*Electrolyte*	*Depo lariser*	*e.m.f. in volts*
Voltaic cell	Copper	Zinc	Dil H_2SO_4	Nil	1.05
Daniell cell	Copper	Zinc	Dil H_2SO_4	$CuSO_4$	1.1
Leclanche cell	Carbon	Zinc	NH_4Cl	$MnO_2 + C$	1.5
Dry cell	Carbon	Zinc cylinder	Paste of NH_4Cl, $ZnCl_2$, flour and plaster of paris	Mixture of MnO_2, Carbon and NH_4Cl	1.45
Lead accumulator	PbO_2	Pb	H_2SO_4	Direct and reverse chemical reaction	2.1
Alkali accumulator	Nickel oxide	Fe	KOH	Direct and reverse chemical reaction	1.35

Differences Between Primary and Secondary Cells

We may notice the following points of difference between a primary and a secondary cell

(i) The chemical reactions (responsible for converting chemical energy into electrical energy) of a primary cell are of *non-reversible nature,* while those of a secondary cell, are of *reversible nature.* We express this by

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saying that whereas a secondary cell can be charged again and again, after use (within certain limits, of cour the primary cell cannot be charged again after its constituent chemicals have once been 'used up.

(ii) The internal resistance of a secondary cell is usually very low compared to that of a primary cell.

(iii) The *ampere – hour* capacity of a secondary cell (*i.e.*, its overall capability of supplying a given cur for a certain length of time) is usually much more than that of a primary cell.

(iv) The secondary cell is (almost) free from the defects of *local action and polarisation.* These defects problematic in the simplest form of the primary cell (the voltaic cell) and are minimized (by using a suita depolarizer) in the other improved forms of the primary cells.

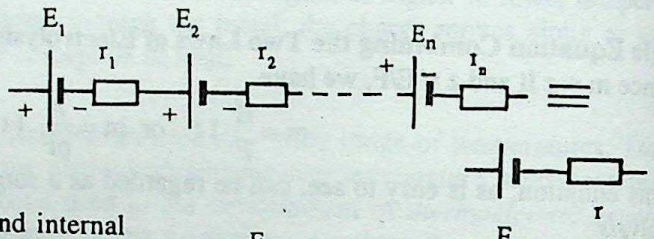
(v) The e.m.f. associated with the acid accumulator form of the secondary cell is more than that associa with the usual (often used) primary cells like the 'Daniell and the Leclanche cell.

Series Combination of n Cells :

When n cells of e.m.f. E_1, E_2,..... E_n and internal resistance r_1, r_2. ...., r_n, are connected in series, t equivalent e.m.f. E and the equivalent internal resistance r are given by

$$E = \sum_{i=1}^{n} E_i$$

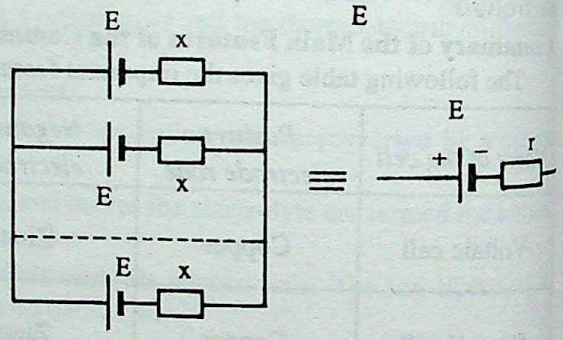
and $$r = \sum_{i=1}^{n} r_i$$



Parallel Arrangement of 'n Identical Cells :

When n identical cells, each of e.m.f. E and internal resistance x, are connected in parallel, the equivalent e.m.f. E and the equivalent internal resistance r are given by

$$E = E \quad \text{and} \quad r = \frac{x}{n}$$

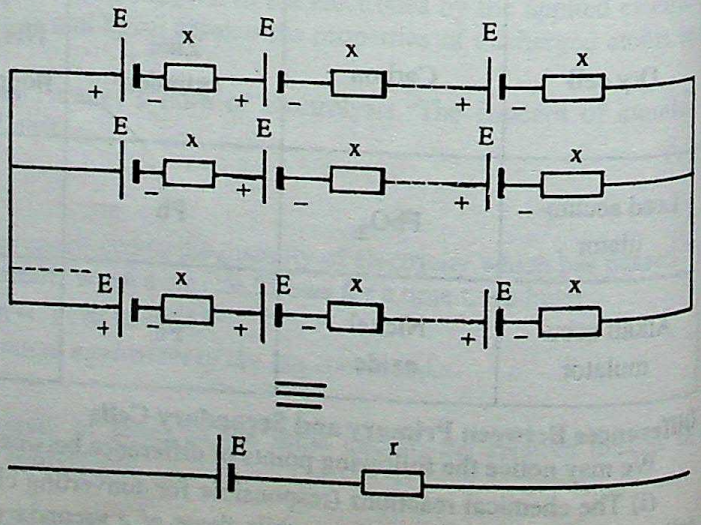


It is interesting to note that we do not have any simple general result for the equivalent e.m.f. and internal resistance of n *different* cells, connected in parallel

The problem, involving such an arrangement, has to be solved, in its given context, through the use of Kirchoff's laws.

Mixed Arrangement of 'N' Identical Cells

When N identical cells are connected in m rows, each containing n cells ($N = m \times n$), we refer to this arrangement as a *mixed* arrangement of the cells. For such a mixed arrangement, the equivalent e.m.f. E and the equivalent internal resistance r are given by $E = nE$ and $r = \frac{nx}{m}$



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The Arrangement for Drawing Maximum Power

It turns out that a given mixed arrangement of N identical cells (N = m × n) in *m* rows, each containing n cells, gives a maximum power to an external resistor R provided the equivalent internal resistance of the arrangement is equal to this external resistor.

Thus, the condition for obtaining maximum power is $\frac{nx}{m} = R$ or $nx = mR$

Combining this with the equation mn = N, we get the values of m and n thus,

$mn = N$ and $\frac{m}{n} = \frac{x}{R}$.

$\therefore m^2 = \frac{Nx}{R} \Rightarrow m = \sqrt{\frac{Nx}{R}}$

Also, $n = \frac{N}{m} = \sqrt{\frac{NR}{x}}$

Thus, by connecting the N identical cells, in parallel, in $\sqrt{\frac{Nx}{R}}$ rows, each containing $\sqrt{\frac{NR}{x}}$ cells in series, we can transfer maximum power to a given external resistor R. We call this result as a particular case of the *maximum power transfer theorem.*

The maximum Power Transfer Theorem

According to this theorem a source of e.m.f. E and internal resistance r, transfers maximum power to an external resistor R which is *equal to* r in value.

SUBJECTIVE QUESTIONS ON UNIT – III

Q.1. *State Joule's law for the rate of production of heat in a coil of wire carrying electric current.* **(1)**

Ans. According to Joule's law, the rate of production of heat, in a coil of resistance R, carrying a current I, is given by.

$$H = I^2 R$$

We also have, H = VI of $H = V^2/R$, where, V (= IR) is the P.d.. across the coil.

Q.2. *Explain on the basis of the free electron theory, the mechanism of heating effects of current.* **(2)**

Ans. When current passes through a conductor, the free electrons are accelerated by the applied field in between collisions. The free electrons gain energy. When these electrons collide with the atoms/molecules of the lattice they transfer their energy to the atoms/molecules, Due to the increase in energy, the thermal agitation of molecules/atoms increases. In other words temperature of the conductor increases or we say heat has been produced.

Q.3. *Obtain from the first principles an expression for the heat developed by the passage of an electric current through a resistance.* **(3)**

Ans. Consider a wire of resistance R, carrying a current I. If V_1 and V_2 are the potentials at the two ends of the wire $(V_1 > V_2)^2$, the electrons would be flowing from end 2 to end 1. Their potential energies at ends 1 and 2 are eV_1 and eV_2 respectively. The gain in p.E. of each of the electrons is, therefore, $e(V_2 - V_1) = eV$, where $V = V_2 - V_1$ is the potential difference between the two ends of the wire.

Corresponding to a current I, the number of electrons, flowing in the wire in a time Δt, is $\frac{I\Delta t}{|e|}$. Hence, the total gain in energy of all the electrons, flowing in a time Δt is

$$\Delta W = \frac{I\,dt}{|e|} eV \quad \therefore |\Delta W| = |V|\, I\,dt$$

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It is this gains in energy of the electrons that appears as heat in the coil. Hence, the rate of production heat, is $\frac{|\Delta W|}{\Delta t} = |V|\ I$

Since, $|V| = IR$, we have $\frac{|\Delta W|}{\Delta t} = I^2R$

Thus, the rate of production of heat, in a coil of resistance R, carrying a current I, is I^2 R. This is *Joul law.*

Q.4. *Heat produced per second in a resistance R is : (i)* $H = i^2 R$ *and (ii)* $H = \frac{V^2}{R}$. *According to relation H increases if R increases but according to relation (ii) H decreases when R increases. Resolve this dilemma.*

Ans. We can easily resolve the dilemma by noting that (i) $H = I^2 R$

Hence, $H \propto R$, *provided I remains constant.* Thus, if (and only if) same current flows through differe resistances, the rate of production will be directly proportional to the resistance.

(ii) $H = \frac{V^2}{R}$ Hence $H \propto \frac{1}{R}$ provided V is constant.

Thus, if (and only if) different resistances are connected across the same potential source, the rate production of heat will be inversely proportional to the value of the resistance. Thus, $H \propto R$ provided I constant and $H \propto \frac{1}{R}$ provided V is constant.

Q.5. *Define electrical power.*

Ans. The rate of production (or consumption) of electrical energy, in a given device, is known as electrical power (P). P = VI, where V is the P.d. across the device when a current I flows through it.

Q.6. *What are the units of electric power ?*

Ans. The units of electric power is the *watt.* We have 1 watt = 1 (volt × ampere)

Q.7. *Is kWh a unit of power?*

Ans. No, the kWh is a unit of electrical energy and *not* of electrical power.

Q.8. *Express 1 kWh in joule.*

Ans. We have

$1\ kWh = 1000\ watt \times 3600\ second = 3.6 \times 10^6\ W\text{-}s = 3.6 \times 10^6 J = 3.6\ MJ$

Thus, 1 kWh = 3.6 MJ.

Q.9. *What changes occur in the heating effect of an electric current if the total resistance is cut to hal keeping the source P.d. constant?*

Ans. When the source P.d.. is constant, the rate of production of heat is given by $H = V^2/R$

Thus, if the resistance is cut to half its original value, the rate of production of heat would become *twice* a much as before.

Q.10. *What will have more resistance: an electric iron of 500W or a bulb of 500W ?*

Ans. Since the rate of energy consumption is the same (= 500W in each case), and the voltage, across both the devices, is also the same, (in household wiring, the different appliances are connected in parallel so that they have the same p.d. across them), their resistances must also be equal to each other.

[We have $P = V^2/R$ or $R = V^2/P$].

Q.11. *Two bulbs have filaments made of same material and of same length. If one is of 40W and other 60W then which one has thicker filament wire ?*

Ans. Since $P = V^2/R$, it follows that the 60 W bulb filament must have a *lower* resistance, Thus, for the same material and same length, the 60W filament wire must be the thicker of the two.

Q.12. *A toaster produces more heat than a light bulb when connected in parallel. Which has greater resistance ?*

Ans. Since $P = V^2/R$, and V is same in both the cases, *R* must be more for the device with lower *power.* Hence, the bulb has the greater resistance.

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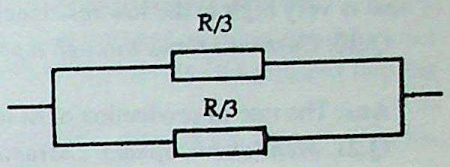
Q.13. *The applied p.d. across a resistance is altered so that heat produced per second increases by a factor of 9. By what factor has the applied p.d increased or decreased ?* **(1)**

Ans. We have $P = V^2/R$. Since R is constant, and P has gone up 9 times, V must have increased by a factor of $\sqrt{9}$ *i.e.* 3 times.

Q.14. *Two heater coils of the same material have wires of radii in the ratio of 2:3 and same length. The two coils are connected in series to a p.d. source. What is the ratio of heat produced per second in the two coils ?*

Ans. Let R_1 and R_2 be the resistances of the two coils. Then

$$R_1 = \rho_1 \cdot \frac{l_1}{\pi r_1^{\,2}} \quad \text{and} \quad R_2 = \rho_2 \cdot \frac{l_2}{\pi r_2^{\,2}}$$



Here $\rho_1 = \rho_2$ and $l_1 = l_2$

$$\therefore \quad \frac{R_1}{R_2} = \frac{r_2^{\,2}}{r_1^{\,2}} = \left(\frac{3}{2}\right)^2 = \frac{9}{4}$$

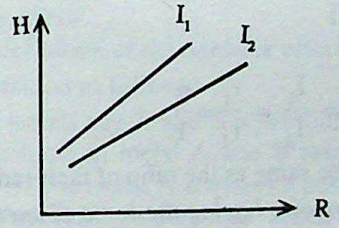
When the coils are connected in series, the current I is the same through both of them.

Hence $H_1 = I^2 R_1$ and $H_2 = I^2 R_2$

$$\therefore \quad \frac{H_1}{H_2} = \frac{R_1}{R_2} = \frac{9}{4}$$

The ratio of heats produced per second, in the two coils, is thus 9 : 4. **(2)**

Q.15. *Fig. below shows graph of H vs R for two currents I_1 and I_2. Is I_1 greater than, less than or equal to I_2 ?* **(1)**



Ans. For a given resistance, $H = I^2R$

Since H is more for the current I_1, it follows that I_1 must be greater than I_2.

Q.16. *By how many per cent will the incandescence of a lamp decrease if the current drops by 2%?* **(1)**

Ans. The incandescence of a lamp is directly proportional to the rate of production of heat in it. Now

$$H = I^2R$$

$$\therefore \quad \text{For same R,} \quad \frac{\Delta H}{H} = 2\frac{\Delta I}{I}$$

$$\text{or} \quad \frac{\Delta H}{H} = 2 \times 2\% = 4\%.$$

Thus, the incandescence of the lamp would decrease by 4%.

Q.17. *The temperature of the filament of an electric lamp is about 2700°C when it glows. Why does not it burn up at such a high temperature ?* **(1)**

Ans. There are two reasons for this :

(i) The filament is present in an atmosphere of nitrogen which does not aid burning.

and (ii)The filament is made of tungsten which has a very high melting point.

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Q.18. *Why should the element of heater get red hot while the cable carrying current remains cold?*

Ans. For the same current (in the connecting cables and the heater element), $H \propto R$.

Now the heater element has a reasonably high resistance while the connecting cables have almost zero resistance. Hence, the former gets red hot while the latter remains cold.

Q.19. *If a battery is short circuited by means of a heavy copper wire, its temperature rises. Why ?*

Ans. A heavy copper wire has a very low resistance. For a given e.m.f., $H \propto \frac{1}{R}$ Thus, the rate of production of heat is very high in the low resistance copper wire and consequently, its temperature rises.

Q.20. *Current I flows through a potential drop V across a conductor. What is the rate of production of heat ?* **(C.B.S.E 1993)**

Ans. The rate of production of heat, H, is given by $H = VI$

Q.21. *Mention two special characteristics of the wire of an electric heater.* **(C.B.S.E 1994)**

Ans. The wire of an electric heater must have

(a) high resistivity. and (b) high melting point.

Q.22. *What will be the ratio of current which will produce in one second the same amount of heat in two wires of the same material and length if the radius of one wire is twice the other ?*

Ans. We have

$$R_1 = \frac{\rho l}{\pi r_1^2} \text{ and } R_2 = \frac{\rho l}{\pi r_2^2}$$

Let currents I_1 and I_2 produce the same amount of heat in the two resistors. Then

$$I_1^2 R_1 = I_2^2 R_2$$

$$\therefore \quad I_1^2 \frac{\rho l}{\pi r_1^2} = I_2^2 \frac{\rho l}{\pi r_2^2}$$

$$\Rightarrow \left(\frac{I_1}{I_2}\right)^2 = \left(\frac{r_1}{r_2}\right)^2 \Rightarrow \frac{I_1}{I_2} = \frac{r_1}{r_2} = \frac{2}{1}$$

Thus, the ratio of the required currents is the same as the ratio of their radii, *i.e.*, 2 : 1.

Q.23. *Equal lengths of silver wire and iron wire having the some diameters are connected in series to form an external circuit across a dry cell. Which wire becomes hotter?*

Ans. The resistivity of iron is more than that of silver. Hence, for the same length and same diameter, the iron wire will have a greater resistance than the silver wire.

It follows that when the wires are connected in series (*i.e.*, carry the same current), the heat produced in the iron wire will be more than that in the silver wire. [For the same current, $H \propto R$]. Hence, iron wire will become hotter.

Q.24. *Under what conditions maximum power is lost by a source of internal resistance r in a load of resistance R ?*

Ans. By maximum power transfer theorem. the required condition is $R = r$

Q.25. *Two heating coils, one of fine wire and the other of thick wire, made of the same material and of the same length are connected in series to a source of electricity. Which of the coil will produce more heat ?*

Ans. The fine wire coil will have a greater resistance. When the coils are connected in series, the current through them is the same. For same current. $H \propto R$. Hence, when connected in series, the fine wire coil will produce more heat.

Q.26. *A constant potential difference is applied to the ends of a graphite rod, whose resistance decreases with rise of temperature. When will the amount of heat given off by the rod be greater, when it is bare or when it is covered with asbestos?*

Ans. When the graphite rod is covered with asbestos (a good insulator), the heat produced in it will not be able to escape and its temperature would rise. This will cause a decrease in its resistance. For a constant p.d., H

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$\frac{1}{R}$. Hence, when the graphite rod is covered with asbestos, the rate of production of heat in it will be more than

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when it is left bare. (In the later case, the heat produced keeps on getting radiated out and the temperature of the rod does not increase much. Hence, its resistance does not decrease much)

Q.27. *The maximum power rating of a 20 Ω resistor is 2 kW. This source is connected directly across 300V d.c source of negligible internal resistance. Explain what happens ?* **(2)**

Ans. The rate of production of heat would be $\frac{V^2}{R} = \frac{300 \times 300}{20} = 4.5 \times 10^3$ watt = 4.5 kW. This is more than double of the maximum power rating (=2kW) of the given resistor. Hence, the resistor would burn out.

Q.28. *A chain of light is composed of 40 pocket torch bulbs connected in series and supplied from the town grid. After one bulb burns itself out, the remaining 39 bulbs are again connected in series and plugged into the town grid. In which case will the room be more brightly lit ?* **(2)**

Ans. Let R be the resistance of each bulb. The total rates of production of heat, in the case of 40 bulbs and 39 bulbs, are

$$H_1 = \frac{V^2}{40R} \text{ and } H_2 = \frac{V^2}{39R} \quad \Rightarrow \frac{H_2}{H_1} = \frac{40}{39} \Rightarrow H_2 > H_1$$

Thus, the room will be more brightly lit with the 39 bulb chain compared to the 40 bulb chain.

Q.29. *Electric energy is transported at high voltage and low current. Why ?* **(2)**

Ans. The rate of production of heat, in the transmission wires, being I^2R, will be more if electrical energy is transmitted at a higher value of current . This energy gets radiated into atmosphere and, therefore gets lost. Hence, by transmitting energy at high voltages and low currents, we are able to reduce the transmission losses.

Q.30. *What is Seebeck effect ?* **(1)**

Ans. The phenomenon of production of an e.m.f., between the two junctions of a pair of dissimilar metals, when the two junctions are kept at different temperatures, is known as the *Seebeck effect.*

Q.31. *State and explain Seebeck effect.* **(C.B.S.E 1996) (1)**

Ans. Refer to Q. no. 30 for the definition of the Seebeck effect.

The Seebeck effect can be understood as follows:

At a junction of two dissimilar metals say A and B a junction potential is developed. Let n_A and n_B be the number of free electrons per unit volume in metal A and B respectively. Let $n_A > n_B$. Free electrons diffuse across the junction from metal A to B. The metal A acquires a positive potential and B a negative potential. The difference of p.d. across A and B is the junction potential. When both junctions of a thermocouple are at same temperature the junction potentials at the two junctions are equal in magnitude. The two are connected in opposition to one another. The net e.m.f. therefore is zero. However, if the two junctions are at different temperatures, there is a net p.d. in the circuit. Let e_1 and e_2 be the junction potential at junctions J_1 and J_2 having temperatures T_1 and T_2 the net thermo e.m.f. e, is $e = e_1 - e_2$

Q.32. *Why is the thermo e.m.f. very small ?* **(2)**

Ans. The thermo e.m.f. equals the difference in the junction potentials developed at the two junctions. The rate of change of junction potentials with temperature is quite small. This is due to the small change in the number of free electrons per unit volume due to change of temperature.

Q.33. *Which of the two thermocouples Sb-Bi or Cu-Fe, produce the maximum e.m.f. for the same temperature difference between hot and cold junction ? Give reason for your answer.*

(C.B.S.E 1995 Comptt.) (2)

Ans. The Sb-Bi thermocouple produces a much greater thermo e.m.f. than a Cu-Fe thermocouple for the same temperature difference between its hot and cold junctions.

This is because the metals Bi and Sb metals are the two extreme metals of the Seebeck series. It is well known that the farther apart the two metals are in the Seebeck series, the more is the thermo e.m.f. produced for the same temperature difference between the hot and the cold junctions.

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Q.34. *Give the direction of thermo electric current at the cold junction of copper bismuth thermocouple.*

Ans. Bismuth is the starting point of the Seebeck series. Since copper occurs later in this series, the thermoelectric current will flow from copper to bismuth at the hot junctions. Hence, it will flow *from bismuth to copper at the cold junction.*

Q.35. *Give the direction of thermo electric current at the cold junction of platinum lead thermo couple.*

Ans. Platinum occurs earlier in the Seebeck series than lead. Hence, in a platinum lead thermocouple, the thermoelectric current will flow *from platinum to lead at the cold junction.*

Q.36. *Which of the two (i) an antimony bismuth thermocouple and (ii) a copper iron thermocouple is more efficient ?*

Ans. An antimony-bismuth thermocouple is more efficient than a copper iron thermocouple. This is because for the same difference of temperature across junctions, the thermo e.m.f. produced in antimony-bismuth thermocouple is more than that in copper-iron thermocouple.

Q.37. *The cold junction of a copper-iron thermo couple is at 0 °C while the hot Junction is at 600 °C. The temperature of inversion is 550 °C for this thermocouple. What is the direction of the thermoelectric current in the thermo couple. Give reasons for your answer.*

Ans. The temperature of inversion of copper-iron thermocouple when cold junction is at 0 °C is 550 °C. If temperature of hot junction is less than 550 °C, the thermoelectric current flows from *copper-to-iron* at hot junction. When hot junction is at 600 °C the direction of thermo e.m.f. reverses, Therefore, thermoelectric current flows from iron to copper at the hot junction.

Q.38. *Write the expression connecting the thermoelectric e.m.f. of a thermocouple with the temperature difference between its hot and cold junctions.* **(C.B.S.E 1995)**

Ans. Let E be the thermoelectric e.m.f. corresponding to a temperature difference of θ between the hot and the cold junctions. The two are then related by the quadratic relation

$$E = a\theta + b\theta^2$$

Here a and b are constants corresponding to the given thermocouple and $b << a$.

Q.39. *What do you understand by neutral temperature ?*

Ans. The temperature of the hot junction of a given thermocouple, (having its cold junction at a given temperature), at which the thermo e.m.f., produced in it, is a maximum, is known as the *neutral temperature* for the given thermocouple

Q.40. *Give any two factors on which thermo-electric e.m.f. produced in a thermo-couple depends.* **(CBSE 1997)**

Ans. Thermo-electric emf produced in a thermocouple depends upon:

(i)Metals used in forming thermocouple.

(ii)Temperature difference between the junctions.

Q.41. *What is Seebeck coefficient?*

Ans. See back coefficient is the rate of change of a thermo-emf with the temperature difference of two junctions of a thermo-couple.

Q.42. *State Seebeck effect. Mention two factor on which (i) neutral temperature. (ii) inversion temperature depends.* **(CBSE 1990)**

Ans. See answers to questions 30 for first part.

(i) neutral temperature depends upon

(a) the nature of materials used in forming thermocouple.

(b) impurities in metal.

(ii) Inversion temperature depends upon

(a) the temperature of cold junction

(b) the nature of materials used in forming the thermocouples.

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Q.43. *Draw the graph showing variation of thermo-e.m.f. of a thermocouple with the temperature difference of its junctions. How does its neutral temperature vary with the temperature of cold junction?* **(CBSE 2000) (2)**

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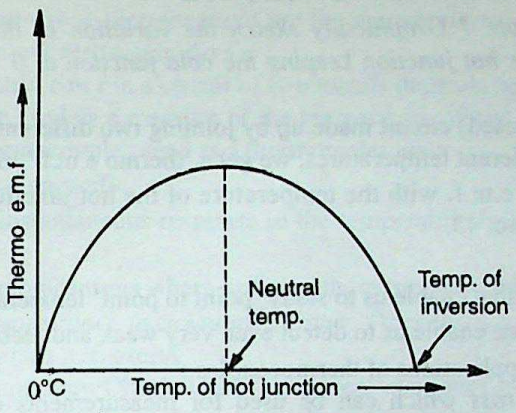
Ans.



Neutral temperature does not depend upon the temperature of cold junction.

Q.44. *Is neutral temperature constant for a given thermocouple ?* **(1)**

Ans. Yes; the neutral temperature has a constant value for a given thermocouple.

Q.45. *What do you understand by temperature of inversion ?* **(2)**

Ans. When the thermo e.m.f., of a given thermocouple, is studied as a function of the difference of temperature between its hot and cold junctions, it is found that the thermo e.m.f. first rises to a maximum and then starts decreasing. It then falls to zero for a particular value of the hot junction temperature before starting to increase again but now in the opposite direction. The temperature of the hot junction, at which this inversion of the direction of the thermo e.m.f. comes about, is known as the *temperature of inversion* for the given thermocouple.

Q.46. *Is temperature of inversion constant for a given thermocouple ?*

Ans. No, the temperature of inversion is not constant for a given thermocouple.

Q.47. *Write relation between the temperature of cold junction (θ_c) temperature of inversion (θ_i) and the neutral temperature (θ_n)*

Ans. The required relation is $\theta_i - \theta_n = \theta_n - \theta_c$ or $2\theta_n = (\theta_i + \theta_c)$

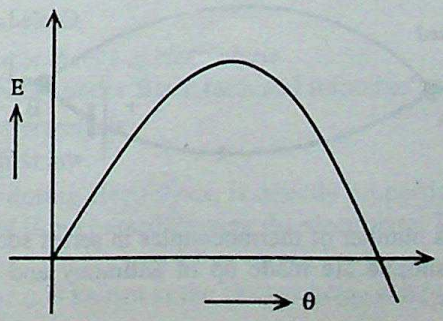
i.e., the temperature of inversion is as much above the neutral temperature, as the neutral temperature itself is over the cold junction temperature.

Q.48. *Name the thermocouple producing maximum thermo e.m.f. for a particular temperature difference between the two junctions.* **(1)**

Ans. The thermocouple producing the maximum thermo e.m.f., for a given temperature difference between its hot and cold junctions, is the *bismuth antimony* (Bi-Sb) thermocouple.

Q.49. *Draw a graph showing variation of the thermo e.m.f. with difference of temperature between the two junctions.* **(C.B.S.E 1993) (1)**

Ans. See answer to Q. no. 43.



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Q.50. *Write the expression connecting the thermo e.m.f. of a thermocouple with the temperature differe of the junctions.* Gandhi Memorial College Of Education Bantalab Jammu **(C.B.S.E 1993)**

Ans. The required expression is $E = a\theta + b\theta^2$ with $b << a$.

Q.51. *What is a thermocouple ? Graphically sketch the variation of the thermo e.m.f. generated a function of the temperature of the hot junction keeping the cold junction at 0 °C. Give two applications of thermocouple.* **(C.B.S.E 1993)**

Ans. A thermocouple is a (closed) circuit made up by jointing two different metals. When the two junctio (of the two metals) are kept at different temperatures, we get a 'thermo e.m.f.' in the circuit.

The variation of the thermo e.m.f. with the temperature of the hot junction (keeping the cold junction 0 °C) has the form sketched in Q no. 43.

Thermocouples are used

(i) as sensitive thermometers that enable us to study 'point to point' temperature over a wide range.

(ii) for making *thermopiles* that enable us to detect even very weak and feeble radiations.

We may also note the following applications of thermocouples :

(i) For making a *thermal cross* which can be used for measurements of weak alternating currents frequencies greater than 10 MHz.

(ii) For developing thermoelectric generators and refrigerators.

Q.52. *What do you understand by thermoelectric power? How does it vary with temperature?*

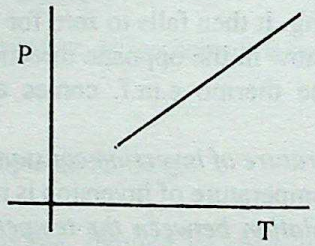
Ans. The rate of change of thermoelectric e.m.f, (E) with the temperature difference, T, (between the h and cold junctions) is known as the *thermoelectric power* (P) Thus.

$$P = \frac{dE}{dT}$$

Since, $E = aT + bT^2$,

we have, $P = \frac{dE}{dT} = a + 2bT$

Thus, P varies with T in a linear way



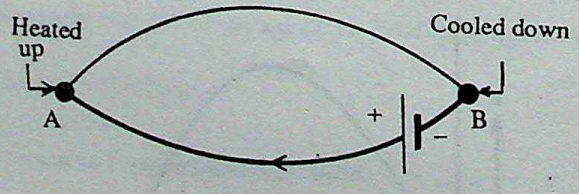
Q.53. *What do you understand by Peltier's effect?*

Ans. When an external battery is used to send current through a thermocouple, it is found that heat absorbed at one junction and evolved at the other. This phenomenon of absorption and evolution of heat, at t junctions, as a result of the passage of an electric current through a thermocouple, is known as the *Peltier effect*.

Thus, as result of the Peltier effect, one of the two junctions will get heated up while the other will co down.

Q.54. *The voltage of a battery in copper-iron thermocouple, is doubled. What will happen to the Pelt heat produced at the junctions ?*

Ans. The Peltier heat produced at the junctions is directly proportional to the current. Hence, on doubli the voltage of the battery, the Peltier heat produced will also get doubled.



Q.55. *What is a thermopile ?*

Ans. A thermopile consists of a number of thermocouples in series such that their effects become additive Usually the thermocouples of thermopile are made up of antimony and bismuth. They are mainly used f measurement of radiation from stars.

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Q.56. *Explain the principle on which thermoelectric refrigerator works.* **(1)**

Ans. The phenomenon of *Peltier effect* is the underlying principle of thermoelectric refrigerators.

Q.57. *Explain how one can use a thermocouple for the measurement of temperature. What advantage a thermocouple has, as a temperature measuring device ?* **(3)**

Ans. Since the thermo-electric e.m.f in a circuit of two metals depends upon the difference in temperature of the junctions, the e.m.f. may be used as a measure of the temperature of one junction if that of the other is kept constant. The advantages of thermocouples used as a thermometer are :

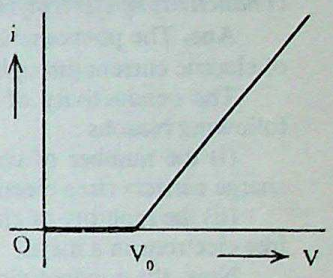
(i) They possess a small heat capacity.

(ii) They make an almost instantaneous response to the temperature because of their conductivity and low heat capacity.

(iii) They can be inserted into positions where ordinary thermometers cannot be easily put.

Q.58. *Platinum electrodes are place in acidulated water. Does this set up obey Ohm's law ? Plot the current versus p.d. graph.* **(2)**

Ans. No, the set up does not obey Ohm's law. The current continues to be zero till a certain value of the applied voltage (say V_0). Once this voltage value is exceeded, the current does vary with voltage in a linear (ohmic) way.



The current versus P.d. graph for this set up (known as a water voltameter) is of the form shown.

Q.59. *State the carriers of current in the following voltameters.*

(i) platinum electrodes in $CuCl_2$ solution.

(ii) platinum electrodes in dilute sulphuric acid.

(iii) platinum electrodes in sodium hydroxide solution. **(2)**

Ans. The carriers of current are.

(i) Cu^{++} and Cl^- ions (ii) H^+ and SO_4^{--} ions (iii) Na^+ and OH^- ions

Q.60. *How is the electrical conductivity of an electrolyte affected with increase of temperature ?* **(C.B.S.E 1995) (1)**

Ans. The electrical conductivity of an electrolyte decreases with an increase in temperature.

Q.61. *Name one strong and one weak electrolyte.* **(1)**

Ans. We may think of water as a strong electrolyte and ethyl alcohol as a weak electrolyte.

Q.62. *In an electrolytic solution, is Ohm's law obeyed ?* **(1)**

Ans. Not quite. The current continues to be zero up to a certain value V_0 of the applied potential. After that, it increases linearly with V, as per Ohm's law.

Q.63. *The passage of a current through a liquid is always accompanied by chemical action. Discuss this statement.* **(2)**

Ans. The passage of a current through an electrolyte is *not* always accompanied by a chemical reaction. Thus, during electro-deposition of silver, on the cathode of a silver voltameter, we may use a pure silver rod as the anode and silver chloride as the electrolyte, During this process, silver gets dissolved from the anode and gets deposited on the cathode. The electrolyte merely helps' in this deposition so that no chemical reaction, as such, may be regarded to have taken place.

Q.64. *Give an account of the ionic theory of electrolysis.* **(3)**

Ans. Refer to the Arrehenius theory under'Basic facts and formulae'.

Q.65. *State Faraday's laws of electrolysis* **(C.B.S.E 1993) (2)**

Ans. According to Faraday's first law.

The mass of an ion, deposited during electrolysis, is directly proportional to the quantity of electricity (the product of the current and its time of flow) passed through the electrolyte. Thus,

$$m \propto I t \text{ or } m = z I t$$

The constant of proportionality, z, is known as the electrochemical equivalent of the given ion.

According to Faraday's second law :

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When a number of electrolytes are connected in series, the masses of different ions deposited, are directly proportional to their chemical equivalent weights. Thus, $\frac{m_1}{m_2} = \frac{E_1}{E_2}$

Q.66. *Define the electrochemical equivalent.* **(CBSE 1998)**

Ans. The electrochemical equivalent, z, of an ion is the mass of this ion deposited when one coulomb of electricity flows through its electrolyte.

Q.67. *Define 1 faraday of charge.*

Ans. One *faraday* (≈ 96500 coulomb) is the quantity of electricity needed to deposit one gram mole of a substance.

I F ≈ 96500 coulomb/gm mole.

Q.68. *Define the term electrolysis. Give two factors which are responsible for the lower electrical conductivity of electrolytes than metals at room temperatures.* **(C.B.S.E 199**

Ans. The phenomenon of electrolysis is the phenomenon of the chemical changes arising from the passage of electric current through a conducting liquid solution.

The conductivity of electrolytes is much lower than that of metals at room temperature, because of the following reasons :

(i) the number of charge carriers (positive and negative ions) is very small compared to the number of charge carriers (free electrons) in a metal.

(ii) the mobility of charge carriers (the ions) in an electrolyte is quite low as compared to the mobility of the free electrons in a metal.

Now, the conductivity of a material is determined both by the number of (free) charge carriers in it and by their mobility, *i.e.*, the drift velocity acquired by them per unit field. Hence, electrolytes have much lower conductivity than metals.

Q.69. *Conductivity of electrolytes is much lower as compared to that of good conducting metals. Give two reasons for this.* **(C.B.S.E. 1993)**

Ans. Refer to the second part of Q. no. 68 above.

Q.70. *Define chemical equivalent and electrochemical equivalent of a substance. Establish the relationship between the two.* **(CBSE 1997)**

Ans. Chemical equivalent: It is the ratio of atomic weight to the valence of a substance.

Electro-chemical equivalent: It is the mass of an element which is liberated by the passage of 1 coulomb of electricity.

Suppose, during electrolysis one mole of a substance of atomic mass M is liberated on the electrode. If N is the Avogardro number, then number of atoms liberated at an electrode = N. If p is the valence of atom involved and e is the charge of an electron then, Charge flowing for deposition of one atom = pe

∴ Total charge flowing for deposition of N atoms = N pe

From Fraday's first law of electrolysis, m = zq.

$\Rightarrow$ M = zNpe (for one mole of atoms)

$$\Rightarrow z = \frac{1}{Ne}\frac{M}{p}$$

$$\Rightarrow z = \frac{1}{Ne}E,\ E = \frac{M}{p}$$ is called chemical equivalent of a substance and Ne is called Faraday's constant.

Q.71. *State Faraday's first law of electrolysis. How is it used?* **(CBSE 1997)**

Ans. See answer to question 65 for 1st part. Faraday's first law of electrolysis is used for measuring electric current on the basis of chemical effect of current.

Q.72. *State Faraday's lqws of electrolysis. Derive the relation connecting chemical equivalent and electro-chemical equivalent of an element.*

Ans. See answers to question 65 and 70. **(CBSE 1999)**

Q.73. *For electrolysis in a pure silver voltameter, is the rate of deposit of silver on cathode equal to the rate of dissolving of silver of the anode in solution.*

Ans. No, not quite. This is because the anode may not be cent per cent pure silver. When electrolysis takes place, the anode not only loses pure silver but also its impurities. However, it is only pure silver that would get

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leposited on the cathode. Hence, the gain in weight of the cathode will be, in general, a little less than the loss in veight of the anode.

Q.74. *The charge passing through an electrolytic solution is reduced to half. By what factor the mass leposited increase or decrease.* **(1)**

Ans. Since the mass deposited is directly proportional to the amount of charge flowing, the mass deposited vill also become half of that deposited before.

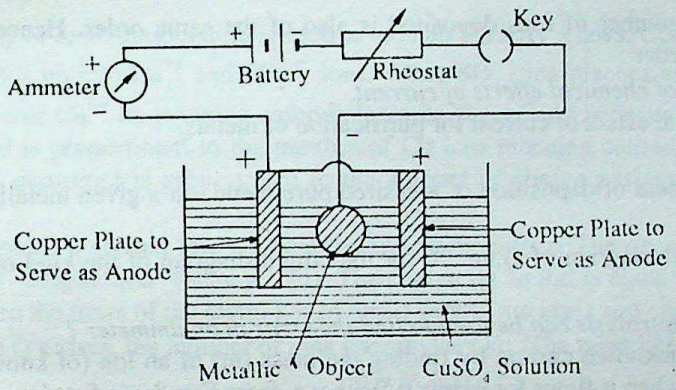
Q.75. *What is the charge required to liberate a mass equal to the electrochemical equivalent ?* **(1)**

Ans. We have $m = zIt = z.q$. When $m = z$, we must have $q = 1$ Hence, we need a *unit charge* to liberate a nass equal to the electrochemical equivalent.

Q.76. *State Faraday's laws of electrolysis. Draw a labelled circuit diagram to illustrate deposition of copper an a given metallic object.* **(CBSE 1995)**

Ans. Refer to the answer to Q. no. 65 for statement of Faraday's laws of electrolysis.

The illustrative diagram of the circuit needed to deposit copper on a metallic object is given below.



Q.77. *The ratio of mass deposited in two copper voltameters in same time is in the ratio of 2 : 3. What is the ratio of current in the two voltameters ?* **(1)**

Ans. We have $m_1 = zI_1t$ and $m_2 = zI_2t$

$$\therefore \quad \frac{I_1}{I_2} = \frac{m_1}{m_2} = \frac{2}{3}$$

Q.78. *Name the liquid which is a good conductor of electricity but does not undergo electrolysis on passage of electric current.* **(1)**

Ans. Mercury. It is a metal that is in the liquid state at ordinary temperatures.

Q.79. *If all liquids furnish ions on conduction of electricity through them, then what about mercury which does not furnish any ions ?* **(1)**

Ans. Mercury is a metal and, like all metals, it has a large number of free electrons. It is these free electrons hat are responsible for the good conducting behaviour of mercury.

Q.80. *What action occurs at the cathode and anode in the electrolysis of (slightly acidulated) water?* **(2)**

Ans. The reactions are as follows :

Ans. The dissociation of water results in the following:

$$4H_2O \rightarrow 4H^+ + 4OH^-$$

At the anode : $4\,OH^- \rightarrow 2H_2 + 2O_2 + 4\,e^-$

At the cathode: $4\,H^+ + 4\,e^- \rightarrow 2H_2$

The overall effect is $4\,H^+ + 4\,OH^- \rightarrow 2H_2O + 2H_2 + O_2$

Q.81. *Why do some covalent salts which are not ionic in solid state become conducting when dissolved in water ?* **(2)**

Ans. This is because of the high dielectric constant (≈ 80) of water. The presence of water, between the ions

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of the covalent salt, reduces the electrostatic force between them by this large factor and this can cause the fall apart. Hence, the covalent salt solution can become conducting.

Q.82. *What is back e.m.f. in an electrolyte ?*

Ans. The positive ions, in an electrolyte, tend to get deposited on the cathode while the negative ions tend get deposited on the anode. They, therefore, tend to make the cathode positive and the anode negative. This tendency, on their part, results in an opposition to the applied external e.m.f.. We can measure the extent of this opposition in terms of a *back e.m.f.*—that is an e.m.f., developed as a result of the deposition of these ions on the electrodes and, having a direction opposite to that of the externally applied e.m.f..

Q.83. *Three voltameters (with platinum electrodes) containing solutions of H_2SO_4, HNO_3 and NaOH respectively give nearly the same value of back e.m.f.. Explain why ?*

Ans. The ions deposited on the cathode and anode respectively, in the three cases are (i) $2H^+$ and SO_4^{--} (ii) H^+ and NO_3^- and (iii) Na^+ and OH^-

In all the three cases, the number of ions deposited is also of the same order. Hence, the back e.m.f. developed are also of the same order.

Q.84. *State one application of chemical effects of current.*

Ans. We can use the chemical effect of current for purification of metals.

Q.85. *What is electroplating ?*

Ans. Electroplating is a process of deposition of a desired pure metal, on a given metallic object, using phenomenon of electrolysis.

We may refer to the labelled diagram of Q.no. 76 for the circuit diagram of the kind of set up needed electroplating.

Q.86. *How the process of electrolysis can be used to find the error in an ammeter ?*

Ans. We can calculate the unknown current by finding the mass (m) of an ion (of known electrochemical equivalent, z) by this current (I) when it flows for a time t. We have, from Faraday's first law :

$$I = \frac{m}{zt}$$

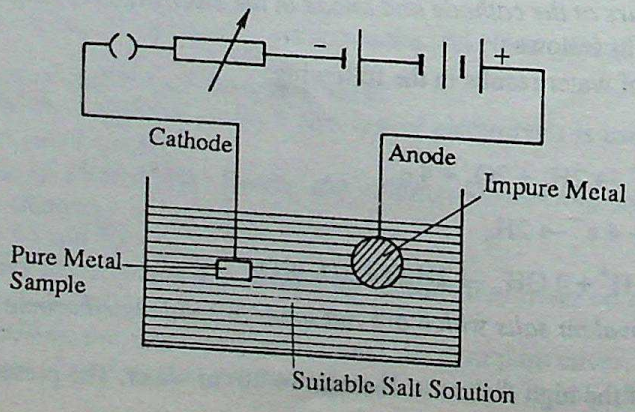
The same current can also be read by the ammeter (to be checked) by putting it in series with voltameter. If the ammeter reading is I′, the error in the ammeter is

$$\Delta I = I' - I$$

The percentage error would be $\frac{\Delta I}{I} \times 100\% = \left(\frac{I' - I}{I}\right) \times 100$

Q.87. *Explain how metals can be purified by using the phenomenon of electrolysis ?*

Ans. We may use the impure metal piece as the anode and a small piece of a sample of the same pure metal as the cathode. By putting an appropriate salt solution (e.g. AgCl in case of silver) of the metal as electrolyte one could set up the voltameter'. When a current is made to flow, only the pure metal will get deposited on the cathode, and the impurities will fall down into the solution. Thus, the impure metal can be purified.



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Q.88. *Give an account, how the laws of electrolysis lead to the concept of atomic nature of electricity.* **(3)**

Ans. Faraday's laws lead to the important concept of the atomic nature of electricity. According to Faraday, 96500 coulomb of electricity deposit one mole of a substance. Also one mole of a substance deposits 6.0254×10^{23} molecules (Avogardro's number). Therefore, during electrolysis, each ion transports the charge 'e' given by

$$e = \frac{96500}{6.0254 \times 10^{23}} \text{ coulomb/atom} = 1.602 \times 10^{-19} \text{ coulomb/atom}$$

Experiments on electrolysis show that ions in electrolysis always carry charges that are integral multiple of the above value. It is reasonable therefore, to assume that the above value of charge is the basic elementary unit of charge. This conclusion was supported by studies in an entirely different field of study — the conduction of electricity through gases. The unit charge is the charge of the electron.

Q.89. *Explain how Faraday's laws of electrolysis can be explained on the basis of ionic theory of electrolysis* **(3)**

Ans. The theory of ionic dissociation is used to explain Faraday's laws. Consider for example electrolysis of $CuSO_4$. $CuSO_4$ splits up into Cu^{++} and SO_4^{--} ions. When SO_4^{--} ion reaches anode, it reacts with Cu^{++} atom to form $CuSO_4$. However Cu^{++} on reaching cathode loses its charge and is deposited on cathode. Obviously mass of copper deposited is proportional to the number of Cu ions reaching cathode. All ions, however, have same charge hence mass deposited is proportional to the amount of charge passing through the electrolyte. This is Faraday's first law.

To explain Faraday's second law we note the following facts.(i)The chemical equivalent of an element is the ratio of atomic weight and valency. (ii) The charge on an ion is equal to valency. (iii) The mass of the ion is nearly equal to the mass of the atom. Let M and q denote the mass and charge of an ion.

When a charge Q passes, the number of ions liberated is Q/q. The mass liberated m, therefore is

$$m = M\,(Q/q)$$

Now M/q = E, the chemical equivalent weight. Therefore $m \propto E$. This is Faraday's second law of electrolysis.

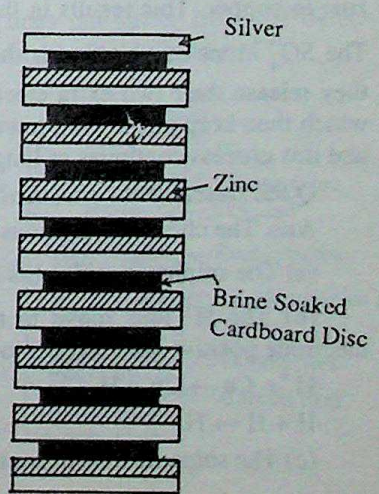
Q.90. *Give an account of the practical applications of the chemical effects of currents.* **(3)**

Ans. The most obvious application is the *electroplating* of cheap metals with chromium, nickel, silver or gold, The article to be coated is made the cathode while a pure specimen of the metal to be deposited acts as the anode, in a voltameter containing a solution of a salt of this metal as the electrolyte, If the article is made of an insulating material it can be given a conducting surface by coating it with graphite.

Electrolysis is used for the preparation of certain compounds and for the purification of metals.

Q.91. *What do you know about the voltaic pile ?* **(1)**

Ans. The voltaic pile consisted of a pile of pairs of silver and zinc discs separated by the brine soaked cardboard discs.



Q.92. *What type of experiments did Galvani carry out ? How did these lead him to the idea of animal electricity ?* **(2)**

Ans. Galvani performed his experiments on *dissected frogs.* In one of his experiments, a dissected frog had a *lightning rod* attached to its head. Another wire dipping in a water well was connected to the leg of the frog, It was observed that as lightning struck, all the *frog muscles momentarily showed violent and multiple contractions.* In another experiment a dissected frog was hung on *iron* railing with *brass* hooks, It was observed that if the leg of the frog came in contact with the iron railing, the frog jumped. We can say that in both the above described experiment the *dead* frog was momentarily restored to "*life*".

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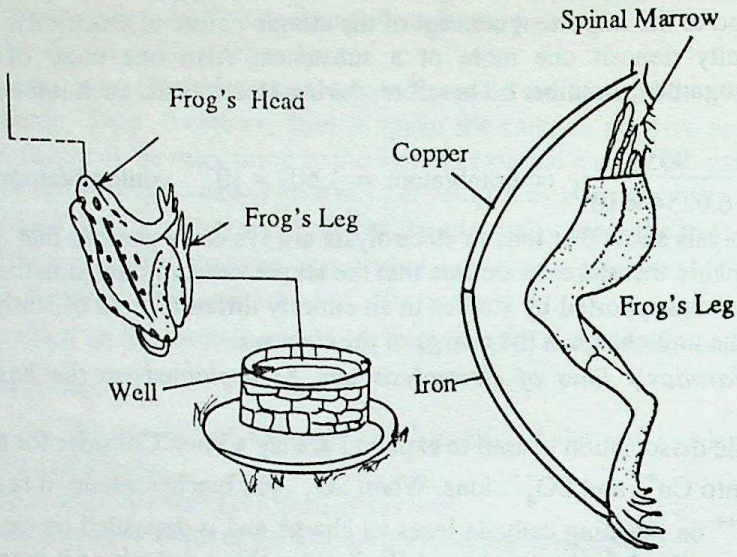
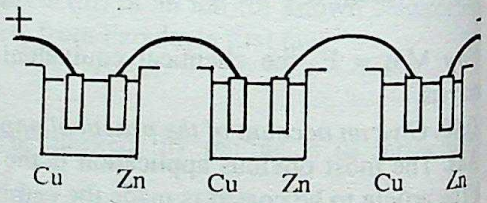


The results of these 'amazing experiments' led Galvani to the idea of some kind of 'animal electricity thought that the muscle and nerve of the dissected frog were akin to a charged Leyden jar and this 'ch animal capacitor' got discharged when the muscle and nerve were joined by a copper and an iron wire, Th this assumption turned out to be wrong, Galvani is credited with performing the first bio physical experimen

Q.93. *What do you know about the Volta's crown of cups ?*

Ans. The 'crown of cups' was made by dipping zinc and copper (or silver) strips in dilute sulphuric acid (contained in small cups) and connecting the zinc strip of one cup to the copper strip of the next (by a copper wire) and so on. Volta showed that an electric current flowed from one (extreme) plate to the other (extreme) plate when they were connected through a conductor (*e.g.*,a metal wire of the human body). This current flow could continue for quite a length of time.



Q.94. *There is no reaction between pure Zn and H_2SO_4. But the reaction starts as soon as Cu and Zn plates of a simple cell are connected externally by conducting wire. Why is it so?*

Ans. As soon as the copper and zinc plates are connected together, there is a movement of electrons f zinc to copper. This results in the movement of the ions of H_2SO_4 (The H^+ and SO_4^{--}) with in the electro The SO_4^{--} ions move towards the zinc plate and it is these that react with zinc to form $ZnSO_4$. In the proc they release their two extra electrons on the zinc plate. The zinc plate thus keeps on receiving extra elect which then keep on flowing towards the copper plate (which has lost an electron to each H^+ ion reaching th and this process continues as long as the two plates are kept connected together.

Q.95. *Describe the chemical reactions taking place in Voltic cell.*

Ans. The chemical reactions in a voltaic cell are described by the following steps :

(a) The sulphuric acid splits into hydrogen and sulphate ions : $H_2SO_4 \rightarrow 2H^+ + SO_4^{--}$

(b) The H^+ ions move to the copper electrode, take free electrons from it and thus, make the cop electrode positive with respect to the solution.

$H^+ + Cu \rightarrow Cu + H$

$H + H \rightarrow H_2$

(c) The sulphate ions move towards the zinc electrode and give its free electrons to it and make $ZnSO_4$

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Q.96. *Mention two defects of a simple cell* **(CBSE 1993)**

Ans. The two main defects of a simple cell are : (i) local action (ii) polarisation.

Q.97. *What do you understand by the term 'polarisation'?* **(2)**

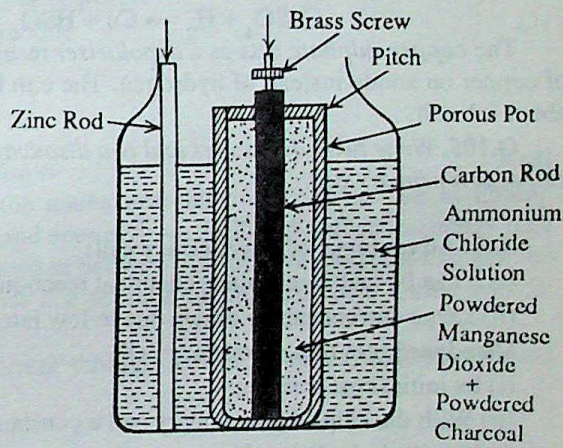
Ans. *Polarisation.* When a simple cell is used to produce an electric current, hydrogen gas bubbles reach its copper rod and get deposited there. After some time, we have a layer of hydrogen bubbles sticking over the copper rod. Now hydrogen does not conduct electricity. It, therefore, reduces or stops the electric current being provided by the cell. We express this by saying that the cell has been *polarised.*

Q.98. *What do you understand by the term 'local action' ?* **(2)**

Ans. *Local action* is a defect of the simple voltaic cell due to the use of commercial zinc in it. Commercial zinc has copper and carbon as impurities and because of these, the sulphuric acid begins to react with the zinc rod as soon as it is put in it. The hydrogen formed begins to pass on to the particles of carbon and copper present in the zinc rod as impurities. This results in the formation of miniature 'local' cells and these consume the zinc rod even when no current is being drawn from the cell by connecting its zinc rod with the copper rod. We call this defect as *local action.*

Q.99. *Describe the action and working of a Leclanche cell. Why does its e.m.f. deminish when it is used to deliver a large current ?* **(3)**

Ans. A Leclanche cell is made by taking a glass container having a saturated solution of *ammonium chloride* in it. An amalgamated zinc rod is dipped in this solution. In the centre of the container, we keep a porous pot filled with a mixture of manganese dioxide and powdered carbon. A carbon rod is fixed inside the *porous pot* in the centre of this mixture.



When the carbon and zinc rods of Leclanche cell are connected, the zinc rod begins to react with the solution of ammonium chloride and releases minute bubbles of hydrogen. As in the simple cell, these hydrogen bubbles get positively charged by releasing their electrons which are deposited on the zinc rod. When these bubbles reach the carbon rod, they 'snatch' electrons from it and make it positively charged.

As the chemical reactions keep on taking place inside the cell, there will be a flow of electrons from the negatively charged zinc rod to the positively charged carbon rod when the two are connected.

Q.100. *What is the purpose of mixing MnO_2 with graphite or carbon particles in a Leclanche cell?* **(1)**

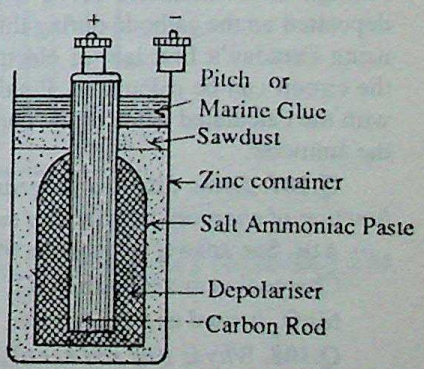
Ans. The graphite or carbon particles are mixed with MnO_2 to make it somewhat conducting.

Q.101. *Why is a Leclanche cell so consistently used whenever an intermittent current is required ?* **(1)**

Ans. A Leclanche cell is useful for intermittent currents because it does not suffer from the defects of polarisation when used intermittently. Further, it is easy to assemble and has a reasonably high e.m.f.

Q.102. *With the help of a suitable diagram, explain the construction and working of a dry cell.* **(CBSE 1995) (3)**

Ans. In a dry cell, we use a *thick paste* of ammonium chloride and glycerine rather than a *solution* of ammonium chloride. It is interesting to note that the name 'dry cell' is somewhat a misnomer because this cell will not work if its paste of ammonium chloride becomes really dry. Besides this difference, there are some other minor points of difference between a dry cell and a Leclanche cell. For example, in a dry cell, we use a *zinc container,* this replaces the glass container as well as the negative zinc rod of Leclanche cell. Also the porous pot of a Leclanche cell is replaced here by a muslin cloth bag and, of course, the ammonium chloride solution is replaced by a *paste* of ammonium chloride and glycerine.



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Because of these changes, the *dry cell* is portable and convenient to use. It is, therefore, the most common used form of the simple electric cell, We use it in torches, radios, electric toys, hair driers, etc.

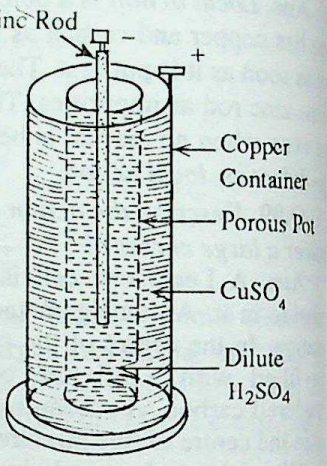
Q.103. *What do you understand by the defect of polarisation in a Lechlanche cell. Draw a labelled diagram of this cell. Explain how is the problem of polarisation overcome in this cell.* **(CBSE 1995 Comptt. 1997)**

Ans. Refer to the answer to Q. no. 97, 99.

Q.104. *Explain, with the help of a labelled diagram, the construction and working of a Daniell cell.*

(CBSE 1995)

Ans. Fig below shows a Daniell cell. It consists of a copper container containing a solution of $CuSO_4$. The container acts as anode. A porous pot containing dilute sulphuric-acid and zinc rod is placed inside the copper container as shown in fig. below.



Working : Due to ionisation of H_2SO_4 and $CuSO_4$, we obtain H^+, Cu^{++} and SO_4^{--} ions. Zinc reacts with H_2SO_4 in porous pot according to reaction

$$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$$

The hydrogen evolved emerges out of porous pot and reacts with $CuSO_4$ according to reaction

$$CuSO_4 + H_2 \rightarrow Cu + HSO_4$$

The *copper sulphate* acts as a *depolariser* resulting in the deposition of copper on anode instead of hydrogen. The e.m.f. of a Daniel's cell is about 1.1 volt.

Q.105. *Write two advantages and two disadvantages of a secondary cell over a primary cell.*

(CBSE 1997)

Ans. Advantages of a secondary cell:

(i) It can be recharged, since chemical reaction is reversible.

(ii) Large current can be drawn due to low internal resistance.

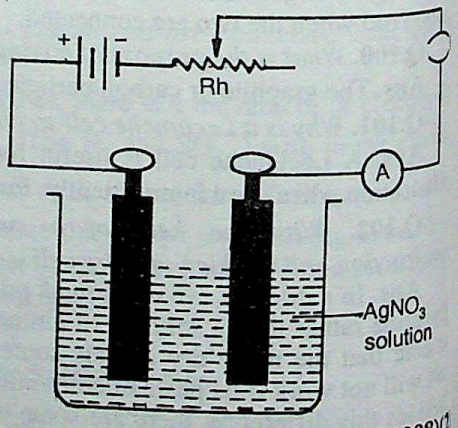
Disadvantages of a secondary cell:

(i) Its initial cost is more.

(ii) With the help of a secondary cell a constant current cannot be maintained.

Q.106. *With the help of a circuit diagram, explain how a silver voltameter can be used to check the accuracy of an ammeter.*

(CBSE 1997 Comptt.)(2)



Ans. Connect the ammeter whose accuracy is to be checked in series with the silver voltameter. With the help of the rheostat, set the ammeter reading at a certain value and allow the current to flow through the voltameter for a certain time. The mass of silver deposited on the cathode during this time interval is measured. Now using Faraday's first law of electrolysis actual value of current in the circuit can be calculated. Finally compare the ammeter reading with the calculated value of the current, which gives the accuracy of the ammeter.

Q.107. *Draw labelled diagram of a Leclanche cell. Write the function of charcoal powder and manganese dioxide used in its porous pot.*

(CBSE 1998)

Ans. See answer to question 99.

Charcoal is mixed with MnO_2 to make it somewhat conducting.

MnO_2 is used as a depolariser.

Q.108. *Why is zinc rod not allowed to remain in the acid when the Daniell cell is not in use ?*

Ans. The Daniell cell has a lower e.m.f. but the depolariser in it is much more effective.

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The zinc rod should not be kept in the acid because it keeps on reacting with the acid because of the impurities present in, it. The impurities cause local cells to be formed on the zinc rod and result in its consumption even when the cell is not in use.

Q.109. *Draw a labelled diagram of a Daniell cell.* **(CBSE 1996) (2)**

Ans. Refer to Q. no. 104.

Q.110. *Draw a labelled diagram of Daniell cell. What is the function of copper sulphate and sulphuric acid solutions used in it?* **(CBSE 1998) (2)**

Ans. See answer to question 104 for 1st part.

In a daniell cell, copper sulphate solution acts as a dipolariser and sulphuric acid solution acts as the electrolyte.

Q.111. *Distinguish between a primary and a secondary cell.* **(2)**

Ans. Secondary cells first store electric energy in the form of chemical energy (during charging) and then use this stored up energy (during discharging). Primary cells, on the other hand, convert chemical energy directly into electric energy.

Q.112. *A primary and a secondary cell have the same e.m.f. Which of these will provide higher value of the maximum current ?* **(1)**

Ans. The secondary cell can provide a higher value of the maximum current because of its higher capacity.

Q.113. *Which type of cell would you want to use if your device required.*
(a) a current of 100 A for 20s and (b) a current of 10 mA occasionally. **(1)**

Ans. We would prefer

(a) a battery of secondary cells or accumulator.

(b) a Leclanche or a dry cell.

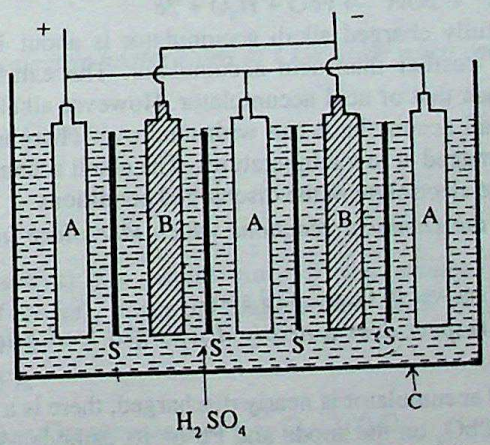
Q.114. *Give the construction and action of a lead accumulator.* **(3)**

Ans. The next fig. shows a lead- acid accumulator. In the *uncharged* cell the electrodes are of $PbSO_4$. During charging the electrodes are converted into *lead-oxide* and spongy lead. In Fig, A indicates *spongy lead* and B indicates lead oxide electrodes. S are the separators placed in between consecutive electrodes so that the plates do not come in contact with one another. The *electrolyte* is a solution of *sulphuric acid* with a *specific gravity* lying between 1.20 to 1.28.

The cell is first *charged* by passing an external d.c. current through it. The chemical reactions during *charging* are :

At anode : $PbSO_4 + SO_4 + 2H_2O \rightarrow PbO_2 + 2H_2SO_4$

At cathode : $PbSO_4 + H_2 \rightarrow Pb + H_2SO_4$



When a fully charged cell is used to supply current to an external load we say it is getting *discharged.* The chemical reactions taking place during discharging are :

At positive plate $PbO_2 + H_2 + H_2SO_4 \rightarrow PbSO_4 + 2H_2O$

At negative plate $Pb + SO_4 \rightarrow PbSO_4$

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The e.m.f. of a fully charged lead accumulator is 2.1 V and its internal resistance is about 0.02 Ω. The cell is almost fully discharged when e.m.f. has fallen to about 1.85 V.

Q.115. *Describe how lead acid accumulator is recharged.*

Ans. Refer to answer no. 114 above.

Q.116. *Describe the changes which take place in a lead storage cell during charging and discharging.*

Ans. Refer to answer no. 114 above.

Q.117. *It is bad for a lead storage cell to charge and discharge at too high rate or for too long at a time. Give reasons.*

Ans. The reversible chemical changes, associated with a lead accumulator, would tend to go *too far* in one direction if the cell is charged or discharged at too high rate for a long time . The cell is thus, likely to get 'damaged'.

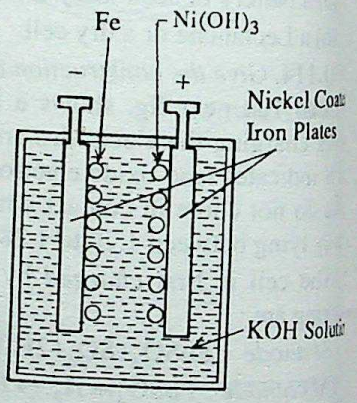
Q.118. *What are secondary cells ? Explain in brief the charging and discharging of a lead accumulator.* **(CBSE 19**

Ans. Secondary cells are those cells that first store electrical energy in the form of chemical energy (during the charging process). They next use this stored up energy during discharging when they convert chemical energy into electrical energy. They are thus, capable of being used 'again and again' (within limits of course) using the same electrolyte and electrodes.

For the charging and discharging process of a lead accumulator, refer to answer to Q. no. 114 above.

Q.119. *Describe the working and action of an alkali accumulator and compare it with the acid accumulator.*

Ans. An alkali accumulator also known as ***Ni-Fe*** cell was developed by Edison. The positive electrode is made from nickle oxide mixed with finely flacked nickel. The negative electrode consists of finely divided iron and yellow mercuric oxide. The materials of respective electrodes are packed into pockets provided in nickel steel grids. A 21% solution of potassium hydroxide is used as electrolyte. A small amount of lithium hydroxide added to improve reaction. The chemical reactions taking place during charging are:



Positive grid $2Ni(OH)_2 + 2OH^- \rightarrow 2Ni(OH)_3 + 2e$

Negative grid $Fe + K^+ + H_2O \rightarrow Fe + KOH - 2e$

During *discharge*, reactions are :

Positive grid $2Ni(OH)_3 + 2K^+ \rightarrow 2Ni(OH)_2 + 2KOH - 2e$

Negative grid $Fe^{++} + 2OH^- \rightarrow FeO + H_2O + 2e$

The e.m.f. of a fully charged alkali accumulator is about 1.3 V. The alkali accumulator is costlier than acid accumulator. The e.m.f. of alkali accumulator is less than that of acid accumulator. However alkali accumulator has a *higher* capacity than acid accumulator. The alkali accumulator can withstand over charging or over discharging or idleness. The alkali accumulator is not damaged at low temperatures. The alkali accumulator are not spoiled even if allowed to stand for longer period in the electrolyte in the discharged conditions.

Q.120. *Describe the chemical reactions which take place in an alkali accumulator during charging and discharging.*

Ans. Refer to the answer to Q. no. 119 above.

Q.121. *In which respect does a nearly discharged lead acid secondary cell differ mainly from a fresh charged cell ?*

Ans. When a lead accumulator is nearly discharged, there is a deposition of $PbSO_4$ on both its plates. This in contrast to having PbO_2 on the anode and Pb on its cathode. Also the density of acid falls below its normal value and the e.m.f. of the cell falls to about 1.8 volt compared to its fully charged value of 2.1 volt.

Q.122. *How is the accumulator kept in a charged condition in a motor car?*

Ans. In a motor car, there is a *dynamo* that constantly keeps on *charging* up its battery. The dynamo keeps working when the car is running and this keeps its battery in a charged condition

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Q.123. *When a primary cell runs down, its active material must be replenished. A secondary cell, however even after long usage can be recharged again. Give the details of ionic reactions at the electrodes of a lead accumulator during discharging and charging and explain this feature of reversibility of a secondary cell.* **(3)**

Ans. Refer to the answer to Q. no. 114 for a look at the charging and discharging reactions in a lead accumulator. This shows the reversible nature of this accumulator.

Q.124. *You are given a primary and a secondary cell of the same e.m.f. From which cell will you be able to draw a larger current and why?* **(CBSE 1994)**

Ans. We would be able to get a larger current from a secondary cell because of its larger capacity.

Q.125. *State one main difference between primary and secondary cells.* **(CBSE 1993) (1)**

Ans. Refer to the answer to Q. no. 111.

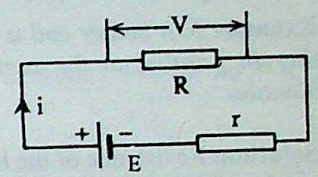
Q.126. *Define the e.m.f. of a cell. Show that the voltage drop across a resistor connected in parallel with a cell, is different from the e.m.f. of the cell.* **(CBSE 1994 Comptt.) (3)**

Ans. We often define the e.m.f. of a cell as the potential difference between its terminals when the cell is on an *open* circuit, *i.e.*, when no current is being withdrawn from it.

Let a cell of e.m.f.. E and internal resistance r be connected across an external resistor R. The current, i, flowing through the circuit is then, as per Ohm's law,

$$i = \frac{E}{R+r}$$

Hence, the p.d. across R is $V = iR = \frac{E}{R+r} \cdot R = \left(\frac{R}{R+r}\right)E$



Thus, V is not equal to E in fact, it is always less than E and could equal E only if r the internal resistance of the cell were zero.

SOLVED NUMERICAL PROBLEMS ON UNIT - III

Example 1. *A current of 5.0A flows through an electric press of resistance 44Ω. Calculate the energy consumed by the press in 5 minutes.* **(CBSE 1993 Comptt.)**

Solution : We have $H = I^2Rt$

Here $I = 5A$, $R = 44\Omega$, $t = 5 \times 60s = 300s$

$\therefore H = 25 \times 44 \times 300\ J = \mathbf{3.3 \times 10^5\ J}$.

Example 2. *How much current will an electric heater rated at 1 kW draw when connected to 220V supply?* **(CBSE 1994 Comptt.)**

Solution : We have, Power = Voltage × Current

$\therefore$ $10000\ W = 200\ V \times I$

$\therefore$ $I = \frac{10000}{220}\ A \cong \mathbf{4.55\ A}$.

Example 3. *Describe what arrangements you would make if you wanted to run a single 50 volt incandescent lamp of a 110 volt circuit. If the lamp takes 0.5 ampere, how much power is taken from the main and how much power is absorbed by the lamp?*

Solution : The lamp rating is 50V, 0.5 A

Hence its power = $50 \times 0.5\ W = 25\ W$ and its resistance = $\frac{50}{0.5}\ \Omega = 100\ \Omega$

Let R be the required resistance to be put in series with the lamp. Since the current, with a 110 V source, must stay at 0.5 A. We have

$$\frac{110}{100+R} = 0.5$$

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or $110 = 50 + 0.5\,R$ or $R = \frac{60}{0.5}\,\Omega = 120\,\Omega$.

Thus, we need a resistance of 120Ω in series with the lamp, the power consumed by the circuit is $P = 110\ V \times 0.5 = \mathbf{55\ W}$.

Out of this only 25 W is consumed by the lamp, the rest is consumed in the resistance R.

Example 4. *An electric motor operating on a 50 V d.c. supply draws a current of 12 A. If the efficiency of the motor is 30%, estimate the resistance of the winding of the motor.*

Solution : Since the current drawn from the 50 V d.c. supply is 12 A, the power supplied by the source is

$$P_0 = 50 \times 12\ W = 600\ W$$

The efficiency of the motor being 30%, the power available is

$$P_0 = 600 \times \frac{30}{100}\ W = 180\ W$$

The rest of the power drawn from the source must be, therefore, getting dissipated as heat within the motor windings. If R be the resistance of these windings, we have $I^2R = (600 - 180)\ W = 420\ W$

$$\therefore R = \frac{420}{I^2}\,\Omega = \frac{420}{12 \times 12}\,\Omega = 2.92\,\Omega \approx \mathbf{2.9\,\Omega}.$$

Example 5. *A heater coil is rated 100 W, 200 V. It is cut into two identical parts. Both parts are connected together in parallel to the same source of 200 V. Calculate the energy liberated per second in the new combination.* **(CBSE 2000)**

Solution: Resistance of the heater coil $= \frac{V^2}{H} = \frac{(200)^2}{100} = 400\,\Omega$

Resistance of each part = 200 Ω

Equivalent resistance of the two parts connected in parallel $= \frac{200 \times 200}{200 + 200}\,\Omega = 100\,\Omega$

Now, $I = \frac{V}{R} = \frac{200}{100} = \mathbf{2A}.$

Energy liberated per second $= I^2R = I^2 \times 100\ J = \mathbf{400\ J}.$

Example 6. *A 24 V battery of internal resistance 4.0Ω is connected to a variable resistor. At what value of the current drawn from the battery is the rate of heat produced in the resistor maximum?*

Solution : Let R be the value of the external resistor. The total resistance of the circuit is then (R+4)Ω so that the current drawn is $I = \frac{24}{R+4}$ ampere

The rate of production of heat in the resistor is $H = I^2\,R = \frac{(24)^2}{(R+4)^2} \cdot R = \frac{576\,R}{(R+4)^2\,R}$

H is thus seen to be a function of R. Clearly, H is maximum when $\frac{dH}{dR} = 0$. Now,

$$\frac{dH}{dR} = \frac{576}{(R+4)^2} \times 1 + \frac{576\,R\,(-2)}{(R+4)^3} \times 1$$

$$= \frac{576}{(R+4)^3}\,[R + 4 - 2R] = \frac{576}{(R+4)^3}\,(4 - R)$$

Thus, $\frac{dH}{dR} = 0$ when $R = \mathbf{4\,\Omega}$.

This is the value of the external resistance for which the rate of production of heat in the resistor is a maximum. It is seen that this value of R is one for which the condition R = r is satisfied.

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Example 7. *Two electric bulbs A and B are marked 220 V 60 W and 220 V 100 W respectively. Which one of the two has greater resistance?* **(CBSE 1998)**

Solution: We know that $P = \frac{V^2}{R} \Rightarrow P \propto \frac{1}{R}$ (for V constant)

Hence, bulb having lower P will have greater resistance i.e., bulb A has greater resistance.

Example 8. *(a) A battery of e.m.f. E and internal resistance r is connected across a pure resistive device (e.g., an electric heater or an electric bulb) of resistance R. Show that the power output of the device is maximum when there is a perfect 'matching' between the external resistance and the source resistance (i.e., when R = r). Determine this maximum power output.*

(b) What is the power output of the source above if the battery is shorted? What is the power dissipation inside the battery in that case?

Solution : (a) The total resistance of circuit being (r + R), the current flowing is

$$I = \frac{E}{r+R}$$

Hence, the power output of the circuit (*i.e.*, the power dissipated in the external resistance R) is

$$P = I^2 R = \frac{E^2 R}{(r+R)^2}$$

P is thus seen to be a function of R. (For a given battery, r and E are constant). Hence, for P to be a maximum, we must have

$$\frac{dP}{dR} = 0$$

Now, $\frac{dP}{dR} = \frac{E^2}{(r+R)^2} \times 1 + E^2 R \cdot \frac{(-2)}{(r+R)^3} \times 1 = \frac{E^2}{(r+R)^3}[r+R-2R]$

$$\therefore \frac{E^2}{(r+R)^3}[r+R-2R] = 0$$

or $r - R = 0 \quad (\because E \neq 0)$

or $R = r$

The power output is thus a maximum when the value of the external resistance equals the internal resistance of the source. We call this as *impedance matching.*

(b) From above, it is clear that when R = 0, P = 0. Hence, the power output of the source become zero when the battery is shorted.

On shorting, the entire power gets dissipated as heat inside the battery. The magnitude of the current in this case being E/r, the power dissipation inside the battery, on its being shorted, has a magnitude P_0 where

$$P_0 = \left(\frac{E}{r}\right)^2 r = \frac{E^2}{r}.$$

Example 9. *(a) An electric motor runs on a d.c. source of e.m.f. E and internal resistance r. Show that the power output of the source is maximum when the current drawn by the motor is E/2r.*

(b) Show that power output of electric motor is maximum when the back e.m.f. is one half the source e.m.f. provided the resistance of the winding of the motor is negligible.

Solution : (a) Let I be the current drawn. The total power drawn from the d.c. source is EI out of which a part I^2r gets dissipated (as heat) in the internal resistance of the source. The power output, P, of the source is then,

$$P = EI - I^2 r$$

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We want P to be a maximum. For this we must have

$$\frac{dP}{dI} = 0. \text{ Now,}$$

$$\frac{dP}{dI} = E \times 1 - r \times 2I = E - 2I$$

Thus, $$\frac{dP}{dI} = 0 \text{ when } I = \frac{E}{2r}$$

Thus, the power output of the source is maximum when the current drawn is E/2r.

(b) Let E_b be the back e.m.f. produced. The net e.m.f. of the circuit, E_n, is then

$$E_n = E - E_b$$

We are given that the motor windings have a negligible resistance. The total resistance of the circuit is then only that due to the internal resistance, r, of the given d.c. source. Hence, the current flowing in the circuit is

$$I = \frac{E_n}{r} = \frac{E - E_b}{r}$$

Now, since the resistance of the motor winding is negligible, there is no power dissipation (as heat) in these windings. Hence, the power output of the motor equals the power output of the d.c. source. The latter is maximum when I = E/2r (proved in part (a) above). Hence, for getting maximum power output from the motor, we must have

$$I = \frac{E - E_b}{r} = \frac{E}{2r}.$$

Example 10. *An electric tea kettle has two heating coils. When one of the coils is switched on, the kettle begins to boil in 6 minutes. When the other is switched on, the boiling begins in 8 minutes. In what time, will the boiling begin if both coils are switched on simultaneously (i) in series, and (ii) in parallel.*

Solution : Let H be the heat required to boil the kettle and R_1 and R_2 the resistance of the two coils respectively.

If V is the supply voltage then, $H = \frac{V^2}{R_1} \times t_1$ J

Given, $t_1 = 6$ minutes,

$\therefore$ $$H = \frac{V^2}{R_1} \times 6 \times 60 \text{ J} \quad \text{...(i)}$$

Similarly, $$H = \frac{V^2}{R_2} \times 8 \times 60 \text{ J} \quad \text{...(ii)}$$

From eqns (i) and (ii) $$\frac{R_1}{R_2} = \frac{6}{8} = \frac{3}{4}$$

When the two coils are connected in series the effective resistance $R_3 = R_1 + R_2$

$$R_3 = R_1 + \left(\frac{4}{3}\right)R_1 = \left(\frac{7}{3}\right)R_1$$

Let t_3 be the time taken by the kettle to boil. Clearly

$$H = \frac{V^2}{R_3} \times t$$

$\Rightarrow$ $$\frac{V^2}{R_1} \times 6 \times 60 = \frac{V^2}{\left(\frac{7}{3}\right)R_1} \times t_3$$

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$$\Rightarrow \quad t_3 = 6 \times \left(\frac{7}{3}\right) \times 60\text{s} = 14 \times 60\text{s} = \textbf{14 minutes.}$$

When the coils are connected in parallel the equivalent resistance R_4 is

$$R_4 = \frac{R_1 R_2}{R_1 + R_2} = \frac{R_1 \left(\frac{4}{3}\right) R_1}{R_1 + \left(\frac{4}{3}\right) R_1} = \frac{4}{7} R_1$$

Let t_4 be the time taken by the kettle to boil. Obviously

$$H = \frac{V^2}{R_4} \times t_4 \Rightarrow \frac{V^2}{R_1} \times 6 \times 60 = \frac{V^2}{(4/7)\, R_1} \times t_4$$

$$t_4 = 6 \times \left(\frac{4}{7}\right) \times 60$$

$$= \frac{24}{7} \text{ minutes} = \textbf{3.43 minutes.}$$

Example 11. *Two wires made of tinned copper having identical cross-section (10^{-6} m^2) and lengths 10 cm and 15 cm are to be used as fuses. Show that the fuses will melt at the same value of current in each case.*

Solution : When a wire is heated, its temperature starts increasing. However, with increasing temperature, the rate of radiation of heat from its surface to the surroundings also goes on increasing. The wire, on heating, therefore, acquires an equilibrium temperature θ at which the rate of radiation of heat from its surface become equal to the rate of supply of heat to it by the source of current.

Let, for a given wire, h be the rate of loss of heat per unit surface area at this temperature θ. If the wire is of radius r and length l, we have

Total surface area of the wire $= 2\pi r l + 2\pi r^2 = 2\pi r\,(l + r) \approx 2\pi r l$,

as $r << l$ for a wire.

Let ρ be the resistivity of the material of the wire. Then, its electrical resistance, R, is given by

$$R = \frac{\rho\, l}{\pi r^2} \quad (\because A = \pi r^2)$$

If the (heating) current has a magnitude I, we have

$$h \cdot (2\pi r\, l) = I^2 R = \frac{I^2 \rho l}{\pi r^2}$$

$$\therefore \quad h = \frac{I^2 \rho}{2\pi^2 r^3}$$

h is thus seen to be independent of l.

Now 'h' depends on the final (equilibrium) temperature θ of the wire. It follows that if θ corresponds to the temperature at which the (fuse) wire melts, it will like, h, be independent of the length of the wire. Thus, fuse made of wires of the same material and the same cross-section will melt at the same value of current independently of their lengths.

Example 12. *Show that when a current is divided between two resistors in accordance with Kirchoff's laws, the heat produced is minimum.*

Solution : Let I_1 and I_2 be the currents in two resistances R_1 and R_2 is parallel and let I be the total current. Applying Kirchoff's first law to the point A, we get

$$I = I_1 + I_2 \qquad \ldots(i)$$

Applying Kirchoff's second law to the mesh AR_1BR_2A, we get

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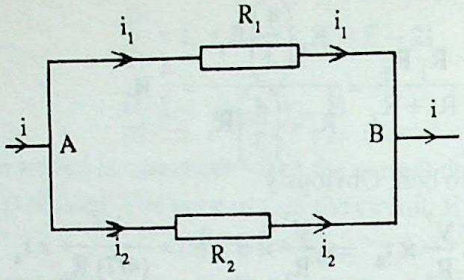
$$I_1R_1 - I_2R_2 = 0$$

$$\therefore \quad I_1/I_2 = R_2/R_1$$



Now, the heat produced in the circuit in t second.

$$H = I_1^2 R_1 t + I_2^2 R_2 t = I_1^2 R_1 t + (I - I_1)^2 R_2 t$$

For H to be minimum, $\frac{dH}{dI_1} = 0$

Now, $$\frac{dH}{dI_1} = 2i_1R_1t + 2(i - i_1)(-1)R_2t$$

$$\frac{dH}{dI_1} = 0 \Rightarrow 0 = 2i_1R_1t - 2(i - i_1)R_2t \quad \text{or} \quad i_1R_1 = (i - i_1)R_2 = i_2R_2$$

$$\therefore \quad \frac{i_1}{i_2} = \frac{R_2}{R_1}.$$

This is in accordance with Kirchoff's second law.

Example 13. *A sensitive microphone cannot withstand currents greater than 0.05 A when connected acr a thermocouple of e.m.f. 8.5 mV, the current in a very low resistance ammeter placed in series in the circ reads 34mA. What is the resistance of the microphone?*

Solution : We are given that corresponding to an applied e.m.f. of 8.5 mV, the current flowing in the circ is 34 mA. Hence

$$\text{Resistance of the circuit} = \frac{8.5 \text{ mV}}{34 \text{ mA}} = \frac{8.5 \times 10^{-3}}{34 \times 10^{-3}} \frac{\text{V}}{\text{A}} = 0.25\ \Omega$$

Since the ammeter is given to be a very low one, the resistance of the circuit is due to the microphone on Hence, resistance of the microphone = **0.25 Ω.**

Example 14. *A potentiometer wire 10 m long having a resistance of 20 Ω is connected in series wit resistnace R and a battery. A Daniell cell of e.m.f. 1.08 V is balanced across the potential difference of R= 2 Ω. The e.m.f. of a thermocouple is balanced across 3m of potentiometer wire. Calculate the value of e.m.f. of thermocouple.*

Solution : Let I be the current through the potentiometer wire and its series resistance R, then the p.d. acro R is

$$V_R = IR = I \times 2160 \text{ V}$$

Since this is used to balance the Daniell cell e.m.f., we have $1{\cdot}08 = I \times 2160$

The resistance per metre of the potentiometer wire is 20/10 ohm m^{-1} or $2\Omega\ m^{-1}$. Since the thermocoup e.m.f say, E gets balanced across a length of 3m (resistance $= 3 \times 2\Omega = 6\Omega$), we have $E = I \times 6$

$$\therefore \quad \frac{E}{1.08} = \frac{I \times 6}{I \times 2160} \Rightarrow E = \frac{6 \times 1.08}{2160} \text{ V} = 3 \times 10^{-3} \text{ V} = 3\text{mV}$$

Thus, the *e.m.f.* of the thermocouple is **3mV.**

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Example 15. *The e.m.f. of a thermocouple, one junction of which is kept 0 °C is given by* $E = at + bt^2$. *Determine the neutral temperature.*

Solution. $E = at + bt^2$ (given)

$$(t°C = (T - 273)\ °K)$$

$$\therefore \quad E = a(T - 273) + b(T - 273)^2 \qquad ...(i)$$

Differentiating eqn. (i) with respect to T, we get

$$\frac{dE}{dT} = a + 2b(T - 273) \qquad ...(ii)$$

At the neutral temperature, $T = T_n$, $\frac{dE}{dT} = 0$

$$\therefore \quad 0 = a + 2b\ (T_n - 273)$$

$$\therefore \quad T_n = \left(273 - \frac{a}{2b}\right)$$

$\therefore$ Neutral temperautre in °C is

$$t_n = T_n - 273 = \left(273 - \frac{a}{2b}\right) - 273 \Rightarrow \mathbf{t_n = -\frac{a}{2b}\ °C.}$$

Example 16. *How long will it take to deposit electrolytically 127 g of copper on the cathode of a copper voltameter by a current of 50 A? (e.c.c. of copper = 0.0003294 g/C).* **(CBSE 1994 Comptt.)**

Solution : We have $m = zIt$

Here $m = 127g$, $z = 3.294 \times 10^{-4}$ g/C, $I = 50A$, $t = ?$

$$\therefore \quad t = \frac{m}{zI} = \frac{127 \times 10^4}{3.294 \times 50} = 7700s \approx \mathbf{2hr\ 8\ minute\ 20\ s.}$$

Example 17. *How long will it take to deposit electrolytically 10.79 g of silver on the cathode of a silver voltameter by a current of 25A? (e.c.e. of silver = 0.001118 g/C).* **(CBSE 1994 Comptt.)**

Solution: We have $m = zIt$

$$\therefore t = \frac{m}{zI} = \frac{10.79}{11.18 \times 10^{-4} \times 25}\ s = 386\ s = \mathbf{6\ minute\ 26\ s.}$$

Example 18. *How long will it take to deposit electrolytically 74.4 g of iron on the cathode of an iron voltameter by a current of 40A? (e.c.e. of iron = 0.0001927 g/c).* **(CBSE 1994 Comptt.)**

Solution :

We have $m = zIt$

$$\therefore \quad 74.4 = 19.27 \times 10^{-5} \times 40 \times t$$

$$\therefore \quad t = \frac{74.4}{19.27 \times 40 \times 10^{-5}} = \frac{74.4}{77.08} \times 10^4\ s = \mathbf{9.7 \times 10^3\ s \approx 2.7\ hrs.}$$

Example 19. *A copper voltameter and an ammeter are connected in series with a battery through a resistance. In 50 minutes, 0.99 g of copper is deposited on the plates. The ammeter reads 0.95 A. Calculate the error in its reading. (e.c.e. of copper is 0.00033 gC* $^{-1}$*)* **(CBSE 1993)**

Solution : We have $m = zIt$

Here, $m = 0.99g$, $t = 50 \times 60\ s = 3000\ s$; $z = 3.3 \times 10^{-4}\ gC^{-1}$

$$\therefore \quad I = \frac{0.99}{3.3 \times 10^{-4} \times 3000}\ A = \frac{9900}{9900}\ A = \mathbf{1A.}$$

The ammeter reads this current as 0.95 A. Hence, the error in the ammeter is **– 0.05** A for a current of 1A. The ammeter thus gives a reading 5% lower than the actual reading.

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Example 20. *To deposit 0.5 kg silver per hour on the cathode of a silver voltameter of resistance 0.70 milli ohm, how much p.d. must be maintained between the plates? (Atomic mass of silver = 108 ; F = 96500 C mole^{-1})* **(CBSE 1993)**

Solution : We have atomic mass of silver = 108; valency = 1

Hence, equivalent weight of silver = 108/1 = 108

$\therefore$ e.c.e. of silver = z = (108/96580) gC^{-1}

Now m = zIt

$$\therefore \quad I = \frac{m}{zt} = \frac{0.5 \times 10^3 \text{ g}}{(108/96500 \text{ gC}^{-1} \times 3600 \text{ s})} = \frac{500 \times 96500}{108 \times 3600} \text{ Cs}^{-1} = 124.1$$

Now I = V/R or V = IR

$\therefore$ Required p.d., = $124.1 \times 0.70 \times 10^{-3}$ volt $\approx$ **86.9 mV.**

Example 21. *In a copper plating experiment 8.25 g of copper is deposited in one and a half hour. What is the ammeter reading connected in series?*

Given one Faraday = 96485 C, atomic mass of copper = 63.54 g.

Solution. Let z be the electro-chemical equivalent of copper. From Faraday's law m = zIt...(i)

If M is the chemical equivalent mass, and F is one Faraday of electricity, then

$$M = z \times F$$

or $$z = M/F \qquad ...(ii)$$

From eqns. (i) and (ii)

$$m = \frac{M}{F} \times I \times t \qquad ...(iii)$$

The electro-chemical equivalent of copper = $\frac{63.54}{2} = 31.77$ g

From eqn. (iii), the current I is $I = \frac{mF}{M \times t} = \frac{8.25 \times 96485}{31.77 \times 1.5 \times 60 \times 60}$ A = **4.76 A.**

Example 22. *A steady e.m.f. of 1.62 V is maintained across two platinum electrodes placed in a solution of $CuCl_2$. At the end of 600 s, the mass of copper deposited is 3.175 g. The back e.m.f. of the voltameter is given to be 1.427 V. Calculate the resistance of the voltameter.* **(CBSE 1996 Comptt.)**

Solution: $V_A = 1.62$V, t = 600 s, m = 3.175 g, $V_B = 1.427$ V,

$$z_{copper} = \frac{\frac{63.5}{2}}{96{,}500} = 0.000329 \text{ gC}^{-1}$$

$$I = \frac{V_A - V_B}{R} = \frac{m}{zt}$$

$$\Rightarrow \quad R = \frac{(V_A - V_B)\, zt}{m} = \frac{(1.62 - 1.427) \times 0.000329 \times 600}{3.175} = 0.0119\ \Omega = \mathbf{0.012\ \Omega}.$$

Example 23. *The potential difference across the terminals of a battery of e.m.f. 12V and internal resistance 2Ω drops to 10 V when it is connected to a silver voltameter. Calculate the silver deposited at the cathode in half an hour. Atomic weight of silver is 107.9 g mol^{-1}.*

Solution: $Z = \frac{107.9}{96500} = 0.0011$, t = 30 min = 1800 sec. **(CBSE 1998)**

Current flowing through the battery = $\frac{\text{e.m.f. of the battery} - \text{p.d. across terminals of the battery}}{\text{internal resistance of the cell}}$

$$= \frac{12 - 10}{2} = 1\text{A}.$$

$\therefore$ The silver deposited = zIt = $0.0011 \times 1 \times 1800$ g = 2.01 g = **2g.**

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Example 24. *A silver and a copper voltameter are connected in series with a 12.0 V battery of negligible ernal resistance. 0.806 g of a silver is deposited in half an hour in the silver voltameter. Calculate:*

(i) magnitude of current flowing in the circuit.

(ii) mass of copper deposited in the copper voltameter during the same period.

[Gives ECE of silver $= 1.12 \times 10^{-8}\ kgC^{-1}$ *and ECE of copper* $= 6.6 \times 10^{-7}\ kg\ C^{-1}$*]* **(CBSE 1998)**

Solution: (i) We know that $m = zIt. \quad \Rightarrow I = \dfrac{m}{zt}$

$$= \frac{0.806 \times 10^{-3}}{1.12 \times 10^{-8} \times 30 \times 60}\ A = 0.000399 \times 10^{5}\ A = 39.9\ A = \mathbf{40\ A.}$$

(ii) Let m be the mass in kg of copper deposited in half an hour when current I ampere is flowing through th silver and copper voltameters in series.

Then, $\dfrac{0.806 \times 10^{-3}}{m} = \dfrac{1.12 \times 10^{-8}}{6.6 \times 10^{-7}} \Rightarrow m = \dfrac{0.806 \times 10^{-3} \times 6.6}{1.12 \times 10^{-1}}\ kg = 4.74 \times 10^{-2}\ kg = \mathbf{47.4\ g.}$

Example 25. *It is desired to deposit 0.254 kg of copper on the cathode of copper voltameter. How long will ake to deposit this amount if a steady current of 100 A is maintained. Relative atomic mass of copper is 63.5 d Faraday's constant is 965000 C mole*$^{-1}$.

Solution : Let z be the electrochemical equivalent of copper. If M is its atomic mass and n be its valency, have

Chemical equivalent weight of copper = M/n

Thus, if F represent, the Faraday constant, we have $z = \dfrac{1}{F}\dfrac{M}{n}$

Substituting values (n = 2 for copper), we get

$$z = \frac{1}{96500\ (C\ mole^{-1})} \times \frac{63.5\ mole^{-1}}{2} = \frac{31.25}{96500}\ g\ C^{-1}$$

Now, from Faraday's first law, $m = zIt \Rightarrow t = \dfrac{m}{ZI}$

Given $m = 0.254\ kg = 0.254 \times 10^{3}\ g = 254\ g,$

$I = 100\ A$ and $z = \dfrac{31.25}{96500}\ g\ C^{-1}$

$$\therefore \quad t = \frac{254 \times 96500}{31.25 \times 100}\ s = \mathbf{7.72 \times 10^{3}\ s.}$$

Example 26. *Calculate the time taken to deposit a coating of nickel 0.05 cm thick on a metal surface by eans of a current of 20 ampere per sq inch of the surface. Nickel is a divalent metal of atomic weight 59 and of nsity 9. Silver has an atomic weight of 108 and an e.c.e. of 1.118 mg/C.*

Solution : Thickness of the nickel to be deposited = 0.05 cm

Area of the coating = 1 sq inch = $(2.54)^2$ sq cm

Density of nickel = 9

Weight of nickel to be deposited = $(2.54)^2 \times 0.005 \times 9$ g

By the second law of electrolysis, we have

$$\frac{\text{E.C.E. of Ni}}{\text{E.C.E. of Ag}} = \frac{\text{Chemical Equivalent of Ni}}{\text{Chemical Equivalent of Ag}}$$

$$\therefore \quad \frac{\text{E.C.E. of Ni}}{1.118 \times 10^{-3}} = \frac{\text{(At. Wt. of Ni)/(Valency of Ni)}}{\text{(At. Wt. of Ag)/(Valency of Ag)}} = \frac{59/2}{108/1} = \frac{59}{216}$$

$\therefore$ E.C.E. of Ni, $z = 1.118 \times 10^{-3} \times \dfrac{59}{216}\ g/C$

By Faraday's first law of electrolysis, we have

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$m = Itz \quad \therefore t = m/zI$

Here $I = 20A$(given)

$$t = \frac{(2.54)^2 \times (0.05) \times 9 \times 216}{1.118 \times 10^{-3} \times 59 \times 20} \text{ s} = 486.4 \text{ s} = \textbf{8 min 6.4 s.}$$

Example 27. *An ammeter was calibrated by connecting it in series with an electrolytic cell conta $CuSO_4$ solution. During a ten minute test the weight of cathode is increased by 2.032 g, the ammeter re being constant at 10 ampere. What correction should be applied to the ammeter at this reading? E.C.E. of 0.0000329 g/C.*

Solution : We have

$$m = zIt \quad \therefore I = \frac{m}{zt}$$

$$= \frac{2.032}{0.000329 \times 10 \times 60} \text{ A} = 10.29 \text{ A}$$

The ammeter reading = 10 A

$\therefore$ Correction needed = $(10.29 - 10)$ A = **0.29 A.**

Example 28. *A silver and copper voltameter are connected in parallel to a 12 V battery of negli resistance. In 30 minutes 1 g of silver and 1.8 g of copper are deposited. At what rate is energy being deli by the battery? Electrochemical equivalent of silver $= 11.2 \times 10^{-7}$ kg C^{-1} electrochemical equivalent of co $= 6.6 \times 10^{-7}$ kg C^{-1}* [L

Solution. Let I_1 and I_2 be the currents through the silver and copper voltameter as shown fig below.

From Faraday's law,

$$m_1 = 10^{-3} \text{ kg} = 11.2 \times 10^{-7} \times I_1 \times 30 \times 60$$

or $$I_1 = \frac{10^{-3}}{11.2 \times 10^{-7} \times 30 \times 60} \text{ A} = 0.495 \text{ A}$$

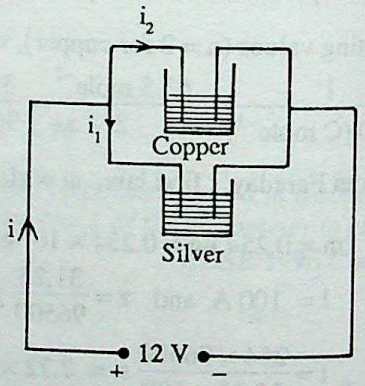
Similarly, $I_2 = \frac{1.8 \times 10^{-2}}{6.6 \times 10^{-7} \times 30 \times 60}$ A = 1.52 A.

The total current I drawn from the source is

$$I = I_1 + I_2 = 0.495 + 1.52 = 2.016 \text{ A}$$

The rate of energy delivered by battery, P, is

$$P = E \times I = 12 \times 2.016 \text{ J/s} \approx \textbf{24.2 J/s.}$$



Example 29. *Three identical cells, each of e.m.f. 2V and internal resistance 0.2 Ω, are connected in se to an external resistor of 7.4 Ω. Calculate the current in the circuit.* **(CBSE 1993 Com**

Solution : Here we have an arrangement of three cells in series. The total e.m.f. of the three cell is

$$E = 3 \times 2V = 6V$$

The total internal resistance of the three cells, connected in series is $r = 3 \times 0.2\ \Omega = 0.6\ \Omega$

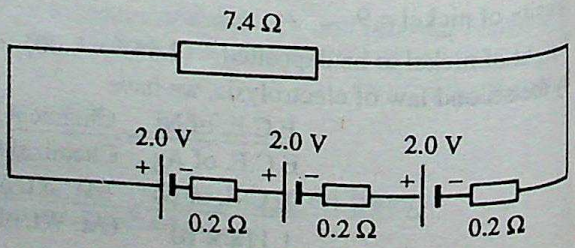
The external resistance used is 7.4 Ω.

Hence, the total resistance of the circuit

$R = (0.6 + 7.4)\ \Omega = 8.0\ \Omega$

By Ohm's law, the current in the circuit is

$I = \frac{E}{R} = \frac{6}{8}$ A = **0.75 A.**



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UNIT – IV

MAGNETIC EFFECTS OF CURRENT

CBSE SYLLABUS CONTENTS

Oersted's experiment, Biot-Savart's law, magnetic field due to a straight wire and a circular loop. Magnetic field due to solenoid (quantitative idea). Force on a moving charge in uniform magnetic field, cyclotron. Force on current carrying conductor and torque on current loop in a magnetic field, forces between two parallel current carrying conductors — definition of ampere. Moving coil galvanometer and its conversion into ammeter and voltmeter.

No. of periods allotted : 10 out of 168

No. of marks allotted : Total of 8 out of 70 along with the Thermal and Chemical Effects of Current.

BASIC FACTS AND FORMULAE

Oersted's Experiment

Oersted was the first to discover that magnetic effects are associated with a current. Ampere then demonstrated the existence of magnetic field due to a current.

Biot-Savart's Law

Biot and Savart investigated the magnetic field of a long straight wire. They found that the magnetic induction at a point is directly proportional to the current strength in the wire and inversely proportional to the distance of the point from the wire.

The Biot-Savart's law enables us to calculate the magnetic induction due to a current carrying element. The law states that the magnitude of **dB** at any point P is

(i) directly proportional to the strength of the current (I) in the element and the length dl of the element.

(ii) inversely proportional to the square of the distance r of the element from the point P, and

(iii) directly proportional to the sine of the angle θ between the current element dl and the vertor **r** from the element to the point P.

Biot-Savart's law is expressed mathematically by the equation.

$$dB = k' \frac{I\, d\, l \sin\theta}{r^2}$$

the constant of proportionality k′ depends on the system of unit chosen. In the S.I. system $k' = \frac{\mu_0}{4\pi}$, where μ_0 is a constant of free space and its value is $4\pi \times 10^{-7} \frac{\text{weber}}{\text{ampere–metre}}$. Hence, the Biot-Savart's law in S.I. units is expressed as

$$dB = \frac{\mu_0}{4\pi} \frac{I\, d\, l \sin\theta}{r^2}$$

The direction of **dB** is in a plane perpendicular to the axis of ***dl*** and is itself perpendicular to the plane determine by ***dl*** and the line joining P and ***dl***. Its sense is given by right hand screw rule.

We express these facts, in a compact form, by the vector equation.

$$\mathbf{dB} = \frac{\mu_0}{4\pi} I \frac{\mathbf{dl} \times \mathbf{r}}{r^3}$$

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Magnetic Field due to a Straight Wire

If there is a straight wire carrying current of I ampere the field due to this wire at a point P, a perpendicular distance from the wire is r, is given by

$$B = \frac{\mu_0 I}{4\pi r} [\cos \alpha + \cos \gamma]$$

However, for an infinitely long wire, B is given by the relation

$$B = \frac{\mu_0 I}{2\pi r} \text{ Wb/m}^2.$$

Magnetic Field due to a Circular Coil

The field due to a circular coil of radius a carrying a current I ampere is

(i) At the centre of the coil $B = \frac{\mu_0 I}{2a}$ Wb/m^2

and (ii) at a point on the axis of the coil distant x from the centre

$$B = \frac{\mu_0}{2} \frac{I a^2}{(a^2 + x^2)^{3/2}} \text{ Wb/m}^2,$$

Magnetic Field due to a Solenoid

The magnetic field due to a straight solenoid of radius *a*, length L having n turns and carrying a current a pont P on the axis of the solenoid is

$$B = \frac{\mu_0}{2} \frac{NI}{L} (\cos \alpha - \cos \beta) \text{ Wb/m}^2$$

where α and β are the angles which the lines joining P to the ends of the solenoid make with its axis.

If the length of the solenoid is very large compared to its diameter, the solenoid is known as standard solenoid. The field at any point P, not near the end, due to a standard solenoid is

$$B = \frac{\mu_0 NI}{L} \text{ Wb/m}^2.$$

Force on a Charged Particle in a Magnetic Field

A moving charged particle in a magnetic field experiences a force. The magnitude of force experienced by a charged particle when it is moving perpendicular to **B** is given by

$$F = q v B$$

and the sense of the force **F** is given by Fleming's left hand rule. However, a charged particle moving in a direction parallel to the direction of the field does not experience a force in a magnetic field.

The force experienced by a charged particle when it is moving with a velocity **v** making an angle θ with the direction of **B** is given by

$$|F| = q B v \sin \theta \text{ or } \mathbf{F} = q (\mathbf{v} \times \mathbf{B}).$$

Definition of the Magnetic Field

Mathematically, the magnetic field vector **B** is defined through the relation

$$B = \frac{F}{q v \sin \theta}$$

B is, thus, the quotient obtained when the force on a moving charge at a point is divided by the product of the charge and its component of velocity normal to **B**.

The direction of the magnetic inductor vector **B** is the direction of the velocity of a moving charge such that it experiences no force. The unit of **B** is newton per coulomb metre per second or weber/metre^2 or tesla.

Lorentz Force

The total electromagnetic force acting on a charge q is given by the expression

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$$\mathbf{F} = q\mathbf{E} + q(\mathbf{v} \times \mathbf{B})$$

F is known as the Lorentz force.

The Cyclotron

The cyclotron is a particle accelerator used to accelerate charged particles like the protons. In it, we use a magnetic field to bend the path of the particles into a circle. An alternating electric potential of frequency $\nu_c = (qB/2\pi m)$ is used to accelerate these particles. We call ν_c as the cyclotron frequency.

Force on a Current Carrying Conductor in a Magnetic Field

The magnetic field exerts a force on a moving charge. Since a current is an assembly of moving charges, a magnetic field will also exert a force on a wire carrying a current.

When a current carrying conductor is placed in a uniform magnetic field it experiences a force. If a wire of length l carries a current of I ampere and a uniform magnetic field B is applied at right angles to it, the force F that it experiences is $F = I\,l\,B$ newton.

The direction of the force is at right angles to both the direction of the conductor and the magnetic field and its sense is given by Fleming's left hand rule. In general if the magnetic field makes an angle ϕ with the direction of the wire, the force F is $F = I\,l\,B \sin\phi$

Both the magnitude and direction of the force can be expressed by the relation $\mathbf{F} = I(\boldsymbol{l} \times \mathbf{B})$, where the length l of the wire is considered to be a vector quantity having the same direction as that of the current.

Torque on a Current Loop in a Magnetic Field

A current loop of area A, carrying a current I, is equivalent to a magnetic dipole of moment μ_m, where

$$\mu_m = IA\hat{n}$$

Here $\hat{n}$ is a unit vector normal to the plane of the coil and in the sense of advance of a right handed screw, rotated in the sense in which the current flowing in the coil.

When placed in a magnetic field a magnetic dipole experiences a torque τ, where

$$\tau = \mu_m \times \mathbf{B}$$

Hence, a current loop, when kept in a magnetic field, experiences a torque τ, where

$$\tau = IA\hat{n} \times \mathbf{B}$$

The torque would tend to bring $\hat{n}$ parallel to **B**. Since $\hat{n}$ is normal to the plane of the coil, the coil would come to equilibrium with its plane normal to the field.

Force between two Parallel Current Carrying Conductors

If we have two parallel wires A and B carrying current situated close to one another, they exert a force on one another. The reason for this is that the current in wire A produces a magnetic field in which wire B carrying another current is situated, and hence, it experiences the force.

The expression for the force is $F = \dfrac{\mu_0 I_A I_B}{2\pi d} l$, where I_B and I_B are the currents in the two wires, l is the length of each wire and d is their separation.

Definition of the Ampere

An ampere is the strength of that constant current which flowing through two parallel, rectilinear, infinitely long conductors of negligible cross-section and placed in vacuum at a distance of 1 metre from each other, produces between these conductors a force of 2×10^{-7} newton per metre of their length.

Moving Coil Galvanometer

A plane rectangular coil of N turns carrying a current I ampere, experiences a couple τ when placed in a uniform magnetic field. The expression for this couple is given by

$$*\tau = I\,N\,A\,B\cos\theta \quad \text{N–m}$$

---

* If the normal drawn on the plane of the coil makes an angle α with the direction of magnetic field, then $\theta + \alpha = 90$ or $\theta = 90 - \alpha$ and $\cos\theta = \sin\alpha$.

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The '*D*' Arsonval moving-coil galvanometer is based on the fact that a rectangular coil placed in a uniform magnetic field, experiences a couple when a current passes through it. Essentially, it consists of a rectangular coil of N turns suspended freely between the pole pieces of a permanent magnet with the help of a wire of phosphor bronze. A small concave mirror is attached to the wire and measures the deflection of the coil with the help of a lamp and scale arrangement. If θ is the deflection of the coil when a current of I ampere passes through it, then

$$I = \frac{c\theta}{NAB\cos\theta},$$

where c is the torsional rigidity of the phosphor-bronze wire. Since, I is not proportional to θ, the rectangular coil is suspended in a *radial magnetic field.* A radial magnetic field is obtained by having curved pole pieces. In a radial magnetic field the magnetic force on the sides of the coil remains perpendicular to the face of the coil, as the coil turns and as consequence.

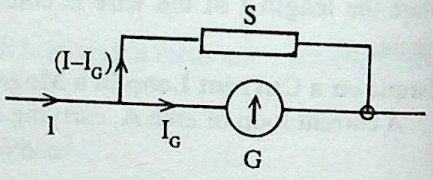
$$I = \frac{c}{NAB}\theta.$$

Conversion of a Galvanometer into an Ammeter and a Voltmeter

We can 'convert' a given galvanometer into an ammeter or a voltmeter by adding an appropriate shunt or series resistance to the galvanometer coil.

Let a galvanometer of resistance G, capable of carrying a maximum current I_G be available

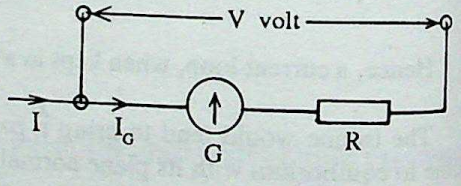
To convert it into an ammeter of range 0 to I ampere, we need to connect a shunt, of resistance S, in parallel with galvanometer coil, where



$$S = G \cdot \frac{I_G}{(I. - I_G)}.$$

To convert the galvanometer into a voltmeter of range 0 to V volt, we need to connect a resistance R is series with it, where

$$R = \left(\frac{V}{I_G} - G\right).$$



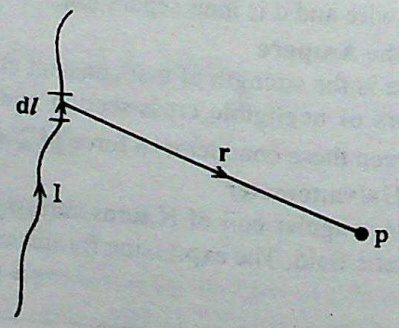
SUBJECTIVE QUESTIONS ON UNIT – IV

Q.1. *Write Biot-Savart's expression for the magnetic field due to a current element.* (1)

Ans. The magnetic field **dB**, due to a current element **dl** is given by

$$\mathbf{dB} = \frac{\mu_0}{4\pi} I \frac{\mathbf{dl} \times \mathbf{r}}{r^3}$$

where **r** is the position vector of the field point P with respect to the current element **dl**.



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Q.2. *What is the value of constant of proportionality in Biot and Savart law in S.I. units.* **(1)**

Ans. The constant of proportionality, in Biot-Savart's law, is $\frac{\mu_0}{4\pi}$ and it has a value of 10^{-7} tesla-metre/ampere.

Q.3. *Show that 1T = 1 N/A-m.* **(1)**

Ans. We have the result, force = charge × charge velocity × magnetic field

Now, charge is to be measured in ampere-sec and the velocity is in metre/sec.

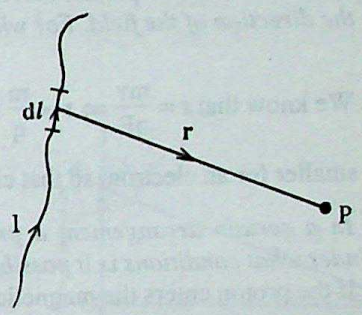
Hence, newton = ampere-sec × $\frac{\text{metre}}{\text{sec}}$ × tesla

$$\therefore \quad 1T = \frac{N}{A\text{-}m}$$

Q.4. *Biot and Savart law can be used to calculate the magnetic field due to a current carrying conductor of any shape and geometry. Explain.* **(2)**

Ans. Biot-Savart's law gives the magnetic field due to a current element **dl**.

$$\mathbf{dB} = \frac{\mu_0}{4\pi} I \frac{\mathbf{dl} \times \mathbf{r}}{r^3}$$

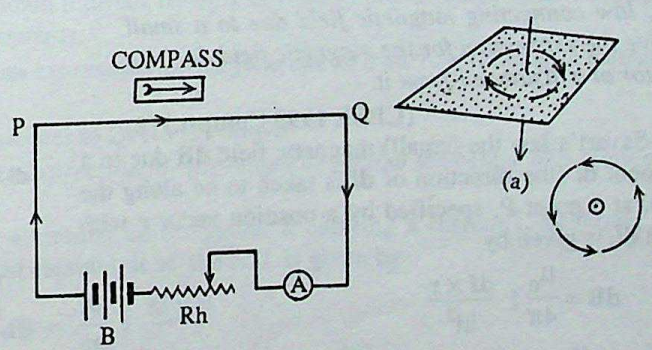


By integrating this expression, over the full current carrying conductor, we can get the magnetic field due to a current carrying conductor of any shape and geometry.

$\therefore$ We get $\mathbf{B} = \frac{\mu_0}{4\pi} I \int \frac{\mathbf{dl} \times \mathbf{r}}{r^3}$.

Q.5. *Describe the essential details of Biot and Savart experiments. Explain Biot and Savart law for the calculation of intensity of the magnetic field due to a current element. Show the Biot and Savart law can be used to calculate the magnetic field due to the current carrying element of any shape and geometry.* **(3)**

Ans. Biot and Savart investigated experimentally, the magnetic field produced by a straight long wire using the arrangement shown in fig. below PQ is the long straight wire carrying current and the compass needle detects the magnetic field it produces. The fact that compass needle is deflected when a current passes through



PQ is indicative of the magnetic field produced by the current. Let PQ be made to pass through a piece of card-board such that it is perpendicular to the plane of the card-board and iron filings are spread on the board. When current passes through PQ, the filings arrange themselves in concentric circles as shown in fig. below. These circles indicate the lines of force.

Quantitative studies of the magnetic field were carried out using a small vibration magnetometer. Biot and Savart found that the magnetic field is (i) *directly proportional to the current,* and (ii) *inversely proportional to the distance from the wire.* These results form the basis of the *Biot-Savart's law.*

For answers to the second and third parts of this question, refer to question no. 1 and 4 above.

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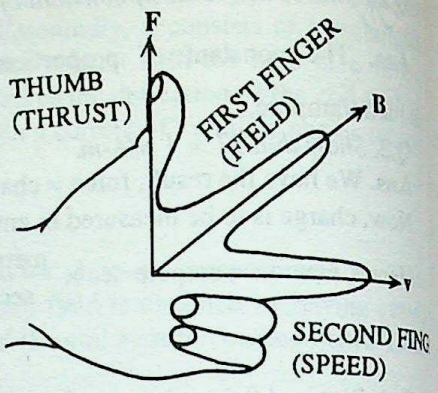
Q.6. *State Fleming's left hand rule.* **(1)**

Ans. This rule is used to find the direction of the force, on a moving charge, in a magnetic field.

Stretch the thumb and the first two fingers so that they are mutually perpendicular to one another. Let the first finger point in the direction of field, the second finger point along the speed (direction of motion) of charged particle. The thumb gives the direction of thrust (force) on the charged particle.



Q.7. *An electron and a proton moving with the same speed enter the same magnetic field region at ri angles to the direction of the field. For which of the two particles will the radius of the circular path be small* **(CBSE 1998)**

Ans. We know that $r = \frac{mv}{qB} \Rightarrow r \propto \frac{m}{q}$ (for v and B constant)

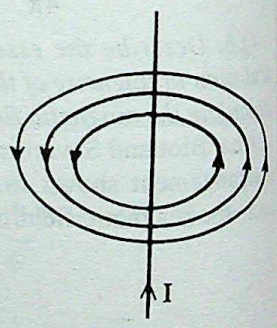
$\frac{m}{q}$ is smaller for an electron, so that circular path described by the electron will be smaller.

Q.8. *In a certain arrangement a proton does not get deflected while passing through a magnetic fi region. Under what conditions is it possible?* **(CBSE 1997)**

Ans. If the proton enters the magnetic field along the field direction, the proton will not get deflected.

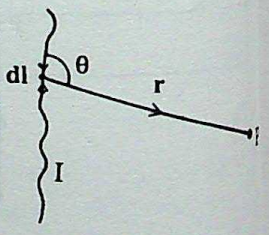
Q.9. *Show the configuration of the lines of force of magnetic field due to a straight current carrying conductor.* **(1)**

Ans. The lines of force of the magnetic field of a straight current carrying conductor are concentric circle centered on the wire.



Q.10. *State Biot-Savart, law connecting magnetic field due to a small current carrying element. Give the expression for the magnetic field due to a straight long current conductor at a distance r from it.*

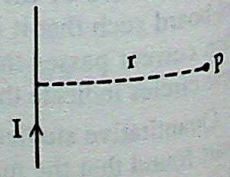
(CBSE 1993 Comptt.) (2)



Ans. According to Biot-Savart's law the (small) magnetic field **dB** due to a current carrying (small) element **dl** (the direction of **dl** is taken to be along the direction of flow of current), at a point P, specified by a position vecor **r** with respect to the current element **dl**, is given by

$$\mathbf{dB} = \frac{\mu_0}{4\pi} I \frac{\mathbf{dl} \times \mathbf{r}}{|r|^3}$$

Thus, the magnitude of **dB** is $\frac{\mu_0}{4\pi} \frac{I\, dl \sin\theta}{r^2}$ and its direction is normal to the plane formed by **dl** and **r** and in the sense of advance of a right handed screw rotated from **dl** to **r**.



The magnetic field B due to a long straight current carrying wire (carrying a current I), at distance r from it is given by

$$dB = \frac{\mu_0 I}{2\pi r}.$$

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Q.11. *Write down the expression for magnetic field at a point distance x from an infinite straight wire carrying a current I.* **(1)**

Ans. The magnetic field is given by $B = \frac{\mu_0 I}{2\pi x}$.

Q.12. *Derive an expression for the magnetic field intensity at a point due to a current carrying straight wire of infinite length.* **(CBSE 1994) (3)**

Ans. Let P be the required point at a distance a from the wire carrying a current I. The (infinitesimal) contribution to the magnetic field at P due to an element **dl** of the wire is

$$\mathbf{dB} = \frac{\mu_0}{4\pi} I \frac{\mathbf{dl} \times \mathbf{r}}{r^3} = \frac{\mu_0 I}{4\pi r^2} dl \sin\theta\,(-\hat{n}),$$

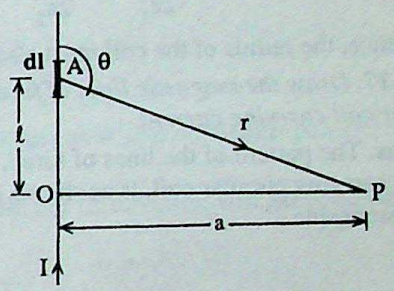
where $\hat{n}$ is a unit vector normal to the plane of the page and directed outwards. Hence,

$$\mathbf{B} = \frac{\mu_0 I}{4\pi}\hat{n} \int \frac{dl \sin\theta}{r^2}$$

Now $\quad l = a\cot(\pi - \theta) = -a\cot\theta$

$\therefore \quad dl = a\,\text{cosec}^2\theta\, d\theta$

Also $\quad r = a\,\text{cosec}(\pi - \theta) = a\,\text{cosec}\,\theta$



$$\therefore \quad \mathbf{B} = \frac{\mu_0 I \hat{n}}{4\pi} \int \frac{a\,\text{cosec}^2\theta \cdot \sin\theta\, d\theta}{a^2\,\text{cosec}^2\theta}$$

$$= \frac{\mu_0 I \hat{n}}{4\pi a} \int \sin\theta\, d\theta = \frac{\mu_0 I \hat{n}}{4\pi a} \left|\cos\theta\right|_0^{\pi}$$

(The limits of θ for an infinite wire are from 0 to π)

Hence, $\quad \mathbf{B} = \frac{\mu_0 I \hat{n}}{4\pi}(-1-1) = \frac{\mu_0 I}{2\pi}\hat{n}$

Thus, $\quad |\mathbf{B}| = \frac{\mu_0 i}{2\pi}$

For the case shown (current flowing upwards), the direction of B is along $\hat{n}$, *i.e.*, normal to the plane of the page and directed inwards.

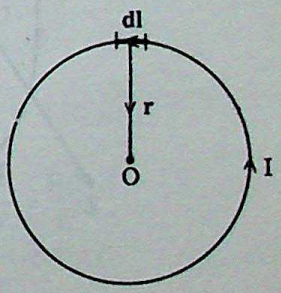
Q.13. *Deduce an expression for the field due to a current flowing in a straight conductor of infinite length.* **(3)**

Ans. Refer to answer to Q. No. 11 above.

Q.14. *Derive an expression for the magnetic field at the centre of a circular current carrying coil.* **(CBSE 1994) (3)**

Ans. Consider a circular coil of radius *a* carrying a current I, as shown below. The magnetic field, at the centre, due to current element **dl** of the coil, is given by

$$\mathbf{dB} = \frac{\mu_0}{4\pi} I \frac{\mathbf{dl} \times \mathbf{r}}{r^3}$$



Here r = a, the radius of the coil. Also **dl** × **r** is directed normal to a plane of the coil, and outwards, for the case shown.

Further **dl** and **r** are at right angles to each other (for all current elements). Hence,

$$\mathbf{dl} \times \mathbf{r} = dl \cdot r \cdot \sin 90^\circ \cdot = dl \cdot a \cdot$$

$$\therefore \quad \mathbf{dB} = \frac{\mu_0}{4\pi} I \frac{dl \cdot a}{a^3} \cdot = \frac{\mu_0 I}{4\pi a^2} dl \cdot$$

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$$\therefore \quad B = \int dB = \frac{\mu_0 I}{4\pi a^2} \cdot \int dl \; l = \frac{\mu_0 I}{4\pi a^2} \cdot 2\pi a \cdot = \frac{\mu_0 I}{2a}.$$

Thus, **B** has a magnitude of $\frac{\mu_0 I}{2a}$ and is directed normal to the plane of the coil and outwards, for the anticlockwise current shown. (For a clockwise current, **B** will be directed normal to the plane of the page and inwards).

Q.15. *What is the expression for the magnetic field at the centre of circular coil of radius a having n turns and carrying a current I_p ?* (1)

Ans. The magnetic field, at the centre of a circular coil of radius a, having n turns, and carrying a current I_p is given by $B = n \cdot \frac{\mu_0 I_p}{2a}$.

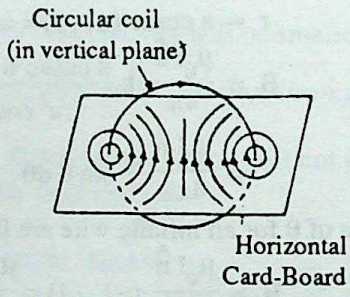
Q.16. *The number of turns in a circular coil is doubled. How the radius of coil be altered so that magnetic field at the centre due the same current remain unaffected.* (1)

Ans. We want $B = \frac{n_1 \mu_0 I}{2a_1} = \frac{n_2 \mu_0 I}{2a_2}$. Since $n_2 = 2n_1$, we must have $a_2 = 2a_1$

Hence, the radius of the coil must also be doubled.

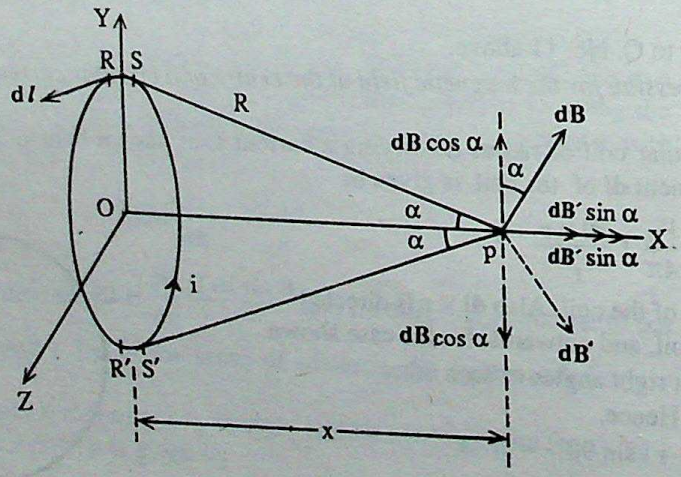
Q.17. *Draw the magnetic lines of force around a circular coil carrying current.* (1)

Ans. The pattern of the lines of force, around a current carrying circular coil, is as shown in the figure alongside.



Q.18. *Using Biot and Savart's law, derive the expression for the magnetic field due to a current carrying circular coil at a point along the axis of the coil.* **(CBSE 1993)** (3)

Ans. Fig. below shows a circular conductor of radius r placed in the y-z plane. The x-axis is the axis of circular coil. P is a point on the axis at a distance x from the centre such that OP = x.



The magnetic field at P is to be calculated. Consider a small element RS = d*l* as shown in fig. The magnetic field **dB** at P due to RS, according to Biot-Savart's law is

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$$|dB| = \frac{\mu_0 I\, dl \sin(\pi/2)}{4\pi R^2} = \frac{\mu_0 I\, dl}{4\pi R^2} \quad ...(i)$$

Note that angle θ between dl and R is $\pi/2$. According to the right-hand screw rule, direction of **dB** is as shown in fig. above. From eqn. (i) it is clear that magnitude of **dB** due to all elements making circular conductor is same. However, *direction* of **dB** due to different elements is different. To obtain **B** a *vector addition* to all **dB** is to be carried out. To do this consider current element R′ S′ · R′ S′ is diametrically opposite to RS. **dB′** is the magnetic field at P due to R′S′. Clearly |**dB**| = |**dB′**|. To add **dB** and **dB′** we resolve them into rectangular components as shown in fig. above. The components dB cos α cancel and the component dB sin α add up. The effective field from one element is dB sin α. The resultant magnetic field **B** is directed along positive x-axis and

$$B = \int dB \sin\alpha = \left[\frac{(\mu_0 I \sin\alpha)}{4\pi R^2}\right]\int dl = \frac{\mu_0 I \sin\alpha\,(2\pi r)}{4\pi R^2} = \frac{\mu_0 I r \sin\alpha}{2R^2} \quad ...(ii)$$

From rt $\angle\Delta$ OPR $\sin\alpha = r/R$, and $R^2 = r^2 + x^2$

$$\therefore \quad B = \frac{\mu_0 I r^2}{2R^3} \quad ...(iii)$$

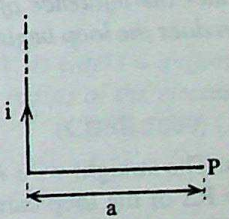
If there are n turns of circular conductor the total field B is

$$B = \frac{\mu_0 n I r^2}{2(r^2 + x^2)^{3/2}}. \quad ...(iv)$$

Q.19. *The current in a long sraight wire is reversed. What is the effect on* **B** *at a particular point?* **(1)**

Ans. There will be no effect on the magnitude of the magnetic field but its direction will get reversed.

Q.20. *Fig. shows a long straight wire carrying current I. Write an expression for magnetic field at point P.*



Ans. The magnetic field at point P, distance a from the wire, is given by

$$B = \frac{\mu_0 I}{2\pi a}$$

Q.21. *A wire of length L is bent into a circle of (i) 2 turns (ii) 4 turns. What is the ratio of magnetic field at the centre of a circle in the two cases when same current passes through them.* **(1)**

Ans. Let r_1 and r_2 be the radii of the circles in the two cases. We then have

$$2 \times 2\pi r_1 = 4 \times 2\pi r_2 = l$$

$$\therefore \quad \frac{r_1}{r_2} = 2$$

Now

$$B_1 = \frac{2 \times \mu_0 I}{2r_1} = \frac{\mu_0 I}{r_1}$$

and

$$B_2 = 4 \times \frac{\mu_0 I}{2 r_2} = 4 \times \frac{\mu_0 I}{2 \times 2 r_1} = \frac{\mu_0 I}{r_1}$$

$$\therefore \quad B_1 = B_2.$$

i.e., the magnetic field, at the centre, is *same* in both cases.

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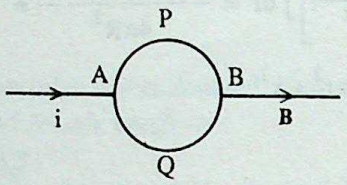
Q.22. *A quadrant of a circle of radius r carries a current I. What is the magnetic field at the centre of quadrant?* (2)

Ans. The magnetic field, at the centre of the quadrant of the circle, will be $\frac{1}{4}$ th that due to the full circle. Hence,

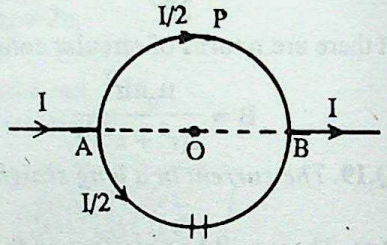
$$B = \frac{1}{4} \cdot \frac{\mu_0 I}{2a} = \frac{\mu_0 I}{8a}$$

Here a is radius of the circle (of which the quadrant is a apart) and I = current flowing.

Q.23. *Consider the circuit shown in fig. below, where APB and AQB are semicircles. What will be the magnetic field at the centre C of the circular loop?* (1)

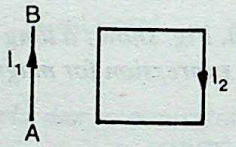


Ans. The currents in the parts APB and AQB will be as shown in fig. below The two halves will, therefore, produce magnetic fields of the same magnitude, but opposite direction, at the centre. Hence, the total field at the centre would be *zero.*

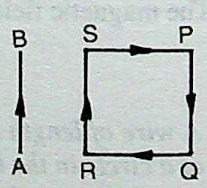


Q.24. *In the figure, the straight wire AB is fixed while the loop is free to move under the influence of the electric currents flowing in them. In which direction does the loop begin to move. Give reasons for your answer.*

(CBSE 1997) (2)



Ans. The straight wire AB is fixed and the loop PQRS is free to move. The side RS of the loop carries current in the same direction as in the wire AB, it will get attracted by AB. The side QP of the loop carries current in the opposite direction as in the wire AB, it will get repelled by the wire AB. Also, RS is nearer to AB than QP, so the force of attraction on the loop is more than the fore of repulsion. Hence, the loop will move towards AB.



Q.25. *A proton and an α-particle of same kinetic energy in turn move through a uniform magnetic field B, in a plane normal to the field. Compare the radii of the paths of the two particles.*

(CBSE 1999) (3)

Ans. We know that $r = \frac{mv}{Bq}$ ...(i)

Also, $K.E. = \frac{1}{2} mv^2 \Rightarrow v = \sqrt{\frac{2.K.E.}{m}}$

Now (i) becomes, $r = \frac{\sqrt{2.K.E.m}}{Bq}$

$\Rightarrow$ $r \propto \frac{\sqrt{m}}{q}$ (for K.E. and B constant)

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$$r_p = \frac{\sqrt{m_p}}{q_p} \text{ and } r_\alpha = \frac{\sqrt{m_\alpha}}{q_\alpha}$$

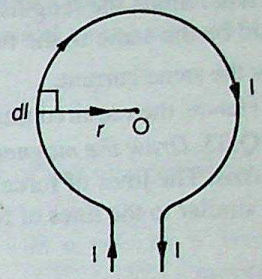
$$\Rightarrow \quad \frac{r_p}{r_\alpha} = \sqrt{\frac{m_p}{m_\alpha}} \times \frac{q_\alpha}{q_p} = \sqrt{\frac{1}{4}} \times \frac{2}{1} = \frac{1}{1} \quad \Rightarrow r_p : r_\alpha = 1 : 1.$$

Q.26. *Using Biot-Savart's law, derive an expression for the magnetic field at the centre of a circular coil of radius r having N number of turns. Indicate the direction of the magnetic field.* **(CBSE 1999, 2000) (3)**

Ans. Consider a circular coil of radius r carrying current I. It consists of a large number of small current elements of length dl.

According to Biot-Sarvart's law, magnetic field at the centre O due to current element dl is

$$dB = \frac{\mu_0 I}{4\pi} \frac{dl \sin q_0}{r^2} = \frac{\mu_0 I}{4\pi} \frac{dl}{r^2}$$

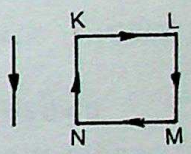


Magnetic field due to all such current elements will point into the plane of the paper. Hence, total field at O is

$$B = \int \frac{\mu_0 I}{4\pi} \frac{dl}{r^2} = \frac{\mu_0 I}{4\pi r^2} \int dl = \frac{\mu_0 I}{4\pi r^2} \cdot 2\pi r = \frac{\mu_0 I}{2r}$$

For a coil of N turns, $B = \frac{\mu_0 NI}{2r}$.

Q.27. *Explain with reason, in which direction does the current loop KLMN move, when kept near an infinitely long straight wire carrying current as shown alongside.* **(CBSE 1999) (3)**



Ans. See answer to question No. 24.

Q.28. *A charge q moving in a straight line is accelerated by a potential difference V. It enters a uniform magnetic field B, perpendicular to its path. Deduce in terms of V, an expression for the radius of the circular path in which it travels.* **(CBSE 2000) (2)**

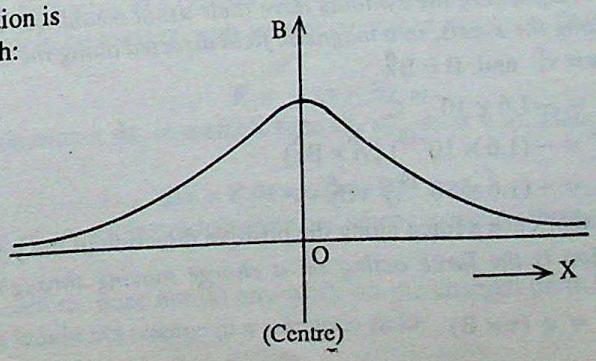
Ans. We have K.E. of the charge $= \frac{1}{2} mv^2$

$$\therefore \frac{1}{2} mv^2 = qV \Rightarrow v^2 = \frac{2qV}{m} \quad ...(i)$$

Also, $qvB \sin 90^\circ = \frac{mv^2}{r} \Rightarrow r = \frac{mv}{qB} \Rightarrow r = \frac{m}{qB} \cdot \sqrt{\frac{2qV}{m}}$ [from (i)] $\Rightarrow r = \sqrt{\frac{2mV}{qB^2}}$

Q.29. *Draw a graph showing variation of magnetic field (B) with the distance (x) of a point on axis from the centre of a circular coil carrying current.* **(1)**

Ans. The required variation is shown by the following graph:



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Q.30. *Write an expression for magnetic field at an axial point inside a long straight solenoid carry current?*

Ans. For an inside axial point, the magnetic field B is given by

$$B = \mu_0 nI.$$

where n = no. of turns per unit length of the solenoid and I = current flowing.

Q.31. *A current is set up in a long copper pipe. Is there a magnetic field (i) inside (ii) outside the pipe.*

Ans. The long copper pipe is like long wire. Hence, there would be a magnetic field outside but that ins would be *zero.*

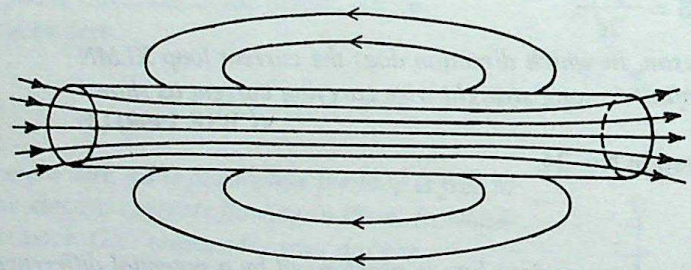
Q.32. *The ratio of length as well as the number of turns in two long straight solenoids is 1 : 2. What is ratio of the magnetic field at the centre of the two solenoids carrying same current?*

Ans. Since the lengths and number of turns increase in the same ratio, the number of turns per unit leng would be the same in the two cases. Since $B = \mu_0 nI$, it would also be the same for the two solenoids when the carry the same current.

Hence, the required ratio is 1:1.

Q.33. *Draw the magnetic lines of force due to long straight solenoid carrying current.*

Ans. The lines of force of the magnetic field, due to a long straight solenoid, are as shown below. (They a very similar to the lines of force of the magnetic field due to a bar magnet).



Q.34. *What is the force on a charge q moving with a velocity* **v** *in a magnsetic field* **B** *?*

Ans. The force **F** is given by $\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$.

Q.35. *Can we say that the component of velocity of a charged particle along the direction of magnetic fie does not change?*

Ans. Yes. This is because the magnetic field exerts a force, on the charged particle, that is perpendicul both to its velocity **v** and the magnetic field **B.** Hence, there is no component of this force along the direction the magnetic field. The velocity component, along the direction of **B,** therefore, does not change.

Q.36. *What will be the path of a charged particle moving along the direction of a uniform magnetic field?*

Ans. The charged particle would keep on moving in a straight line. This is because the force on a charge particle, moving along the direction of a (uniform) magnetic field, is zero.

Q.37. *Given that* $\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$, *where the symbols have their usual meanings. What would be the direction of* **F** *for an electron, moving along the x-axis, in a magnetic field directed along the z-axis?*

Ans. We are given that $\mathbf{v} = v\hat{i}$ and $\mathbf{B} = B\hat{k}$

Also q (for electron) $= -1.6 \times 10^{-19}$ C.

$$\therefore \mathbf{F} = -(1.6 \times 10^{-19})(v\hat{i} \times B\hat{k})$$

$$= +(1.6 \times 10^{-19})\ vB\hat{j}.$$

Thus, the electron would experience a force along the positive direction of the y-axis.

Q.38. *Under what condition is the force acting on a charge moving through a uniform magnetic field minimum?*

Ans. We have $\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$

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$\therefore$ $|\mathbf{F}| = qvB \sin\theta$

Thus, **F** is minimum (= 0) when $\sin\theta = 0$ or $\theta = 0$.

Thus, the charged particle would experience the minimum force (= zero) when it is moving parallel to the magnetic field.

Q.39. *When will the force experienced by a moving charge be maximum in a magnetic field?* **(1)**

Ans. The force is maximum when $\sin\theta = 1$ or $\theta = 90°$.

Thus, the charged particle experiences the maximum force when it is moving at right angles to the direction of the magnetic field.

Q.40. *The force F experienced by a particle of charge q moving with velocity v in a magnetic field B is given by* $\mathbf{F} = q(v \times \mathbf{B})$. *Which pair of vectors are always at right angles to each other?*

(CBSE 1993 Comptt 1998) (1)

Ans. The given formula tells us that the force **F** is perpendicular to the plane formed by the vector **v** and **B**. Hence, the two pairs:

(i) **F** and **v** and (ii) **F** and **B** are always at right angles to each other.

Q.41. *Can a magnetic field set on electron at rest into motion?* **(1)**

Ans. No; a magnetic field cannot bring about any change in the kinetic energy of any charged particle, on which it acts.

Q.42. *In a chamber of uniform magnetic field* **B**, *an electron beam enters with a velocity v. Write an expression for the force experienced by the electrons.* **(CBSE 1993 Comptt.) (1)**

Ans. The force **F**, experienced by any electron of the given electron beam, is given by $\mathbf{F} = \mathbf{e}(\mathbf{v} \times \mathbf{B})$, where e is the charge ($= 1.6 \times 10^{-19}$ C) on the electron.

Q.43. *What is the force on a charge moving along the directon of the magnetic field?* **(CBSE 1994) (1)**

Ans. The force is zero.

(We have $\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$. Since **v** and **B** are along the same direction, $|\mathbf{v} \times \mathbf{B}| = vB \sin 0 = 0$.

Q.44. *Under what condition an electron, moving through a magnetic field, experiences maximum force?*

(CBSE 1994) (1)

Ans. The electron experiences maximum force when it is moving (with a given speed) perpendicular to the direction of the magnetic field.

(Since $|\mathbf{F}| = evB \sin\theta$, we have $|\mathbf{F}|_{max} = evB$, when $\sin\theta = 1$, i.e., $\theta = 90°$).

Q.45. *Why does the picture on a T.V. screen become distorted when a magnet is brought near the screen?* **(1)**

Ans. The magnet exerts a force on the moving electron beam (responsible for picture formation on the screen). This interferes with the force on them due to the incoming picture signal. The picture, therefore, gets distorted.

Q.46. *Is any work done by a magnetic field on a charge moving at right angles to the magnetic field?* **(1)**

Ans. No, the work done by the magnetic field is zero. (The force due to the magnetic field, and the corresponding instantaneous displacement, are always at right angle to each other).

Q.47. *Show that the kinetic energy of a charged particle does not change in a magnetic field.* **(2)**

Ans. Let a charged particle be moving with a velocity **v** in a magnetic field **B**. The force on the charged particle is

$$\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$$

The instantaneous displacement **ds**, in a small time dt, is : $\mathbf{ds} = \mathbf{v}\,dt$. Hence, the work, dW, done by the magnetic field, is

$$dW = \mathbf{F}.\mathbf{ds} = q(\mathbf{v} \times \mathbf{B}) \cdot \mathbf{v}\,dt$$

But $(\mathbf{v} \times \mathbf{B}) \cdot \mathbf{v} = 0$ (The vector triple product vanishes when two of the three vectors are identical).

Hence, $dW = 0$.

The magnetic field, therefore, does not do any work on the charged particle. This means that the kinetic energy of a charged particle would not change in a magnetic field.

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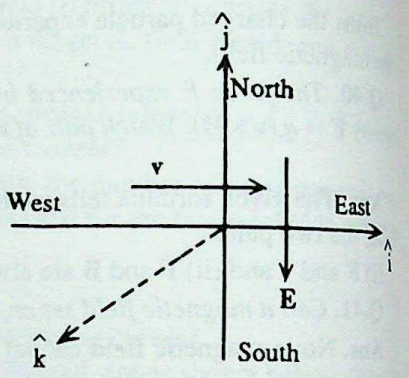
Q.48. *The force experienced by a current carrying wire in an external magnetic field is maximum. What the angle between the magnetic field and the wire?*

Ans. The force magnitude being $F = I l \sin\theta$. The force is maximum, when $\theta = 90°$. Hence, the wire must be at right angles to the magnetic field.

Q.49. *An electron travelling west to east enters a chamber having a uniform electrostatic field in a north-south direction. Specify the direction in which a uniform magnetic field should be set up to prevent the electron from deflecting its straight line path.* **(1)**



Ans. The electrostatic force on the electron would be from south to north, *i.e.*, along $+\hat{j}$. The force due to the magnetic field must, therefore, be from north to south, i.e, along $-\hat{j}$. Now,

$$\mathbf{F} = q(\mathbf{v} \times \mathbf{B}).$$

Here **v** is along $+\hat{i}$. We want $\mathbf{v} \times \mathbf{B}$ to be along $+\hat{j}$, as only then **F** would be along $-\hat{j}$. This is because, q, the charge on the electron, is a negative quantity. With **v** along $+\hat{i}$, and $\mathbf{v} \times \mathbf{B}$ along $+\hat{j}$, it follows that **B** must be along $-\hat{k}$.

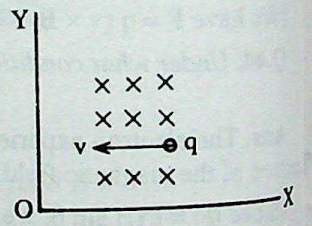
Thus, the magnetic field should be perpendicular to the plane specified by v and E and directed into this plane.

Q.50. *What will be the path of a charged particle moving perpendicular to a uniform magnetic field?* **(CBSE 1993)**

Ans. The path will be a circle in a plane perpendicular to the uniform magnetic field (**B**)

[The radius r of this circle is given by $\frac{mv^2}{r} = qvB$ or $r = mv/qB$]

Q.51. *A point charge q is moving with a speed v perpendicular to a magnetic field B as shown. Explain what should be the magnitude and direction of the applied electric field so that net force acting on the charge is zero.* **(2)**



Ans. Here **v** is along $-\hat{i}$ and **B** is along $-\hat{k}$. We want

$$q(\mathbf{v} \times \mathbf{B}) = -q\mathbf{E}$$

$\therefore\ -\hat{i} \times -\hat{k} = -$ (The direction of **E**) or the direction of

$\mathbf{E} = -(-\hat{j}) = +\hat{j}$

The electric field must, therefore, act along the y-axis.

Q.52. *Is any work done by a magnetic field* **B** *on a charged particle moving at right angles to the magnetic field? If not, how can it deflect the particle?*

Ans. No, the work done is zero.

The magnetic field, at all instants, exerts a force at right angles to the instantaneous direction of motion of the particle. The work done is hence zero. However, the force can keep on deflecting the particle along its normal to its instantaneous velocity.

Q.53. *A magnetic field, that varies in magnitude from point to point, has a direction east to west set up in a chamber. A charged particle enters the chamber and travels undeflected along a straight path with constant speed. What can you say about the initial velocity of the particle?*

Ans. Since the charged particle remains undeflected, the force on it is zero throughout. This is possible only if it moves along, (or antiparallel to) the direction of the magnetic field. The initial velocity of the particle must, therefore, be either from *east to west* or *from west to east.*

Q.54. *Describe the path of a charged particle moving in a uniform magnetic field with initial velocity (i) parallel to the field (ii) perpendicular to the field (iii) at an arbitrary angle with the field direction.*

Ans. (i) When the initial velocity of the charged particle is parallel to the field, it continuous to move straight along its original direction.

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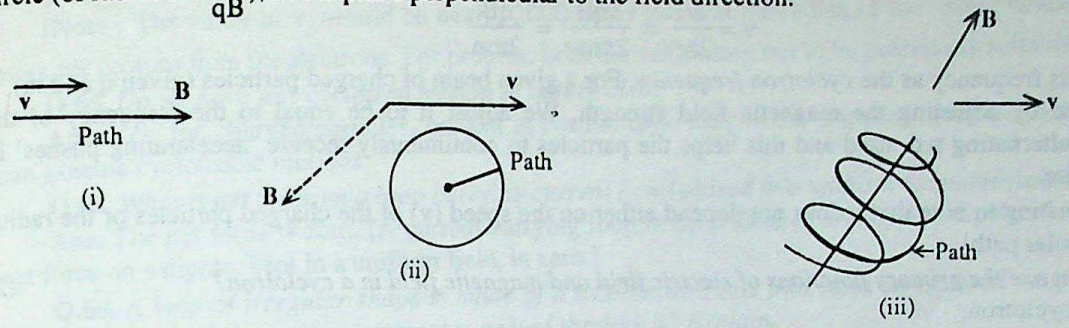
(ii) When the initial velocity of the charged particle is perpendicular to the field, its path gets bend into a circle (of radius $r = \frac{mv}{qB}$), in the plane perpendicular to the field direction.



(iii) When the initial velocity of the charged particle is at an arbitrary angle to the field, its path is a *helical* (spiral) one with the axis of the helix along the direction of the field.

Q.55. *A bean of alpha particles and of protons of the same velocity v enter a uniform magnetic field at right angles to field lines. The particles describe circular paths. What is the ratio of the radii of these circles?*

(CBSE 1993 Comptt.) (2)

Ans. The radius R of the circular path described by a charged particle, of charge q and mass m moving with a velocity v, at right angles to a uniform magnetic field B, is given by

$$\frac{mv^2}{R} = qvB \text{ or } R = \frac{mv}{qB}$$

If follows that $\frac{R_1}{R_2} = \frac{m_1}{m_2} \cdot \frac{q_2}{q_1}$ (for same v and B).

For α-particles and protons, we have $m_1/m_2 = 4/1$ and $q_1/q_2 = 2/1$

$$\therefore \quad \frac{R_1}{R_2} = \frac{4}{1} \times \frac{1}{2} = \frac{2}{1}$$

Thus, $$R_\alpha / R_{proton} = 2 : 1$$

Q.56. *What is Lorentz force? Write an expression for the Lorentz force.* **(2)**

Ans. The force experienced by a charged particle in an electric, or magnetic field, is known as the *Lorentz force.*

Let a charged particle, of charge q, moving with a velocity **v**, enter a region where an electric field **E** and magnetic field **B** are simultaneously present. The total Lorentz force, on the charged particle, is then given by $\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$

We call $q\mathbf{E}$ as the electric part and $q(\mathbf{v} \times \mathbf{B})$ as the magnetic part of the Lorentz force.

Q.57. *A charged particle enters an environment of a strong and non uniform magnetic field varying from point to point both in magnitude and direction and comes out of it following a complicated trajectory. Would its final speed equal the initial speed if it suffered no collisions with the environment?* **(2)**

Ans. Yes, the final speed would equal the initial speed, if there are no collisions etc., i.e., if there is no wastage of energy. This is because a magnetic field, no matter what its nature, cannot bring about any increase in the kinetic energy of a charged particle moving through it.

Q.58. *What is the principle of a cyclotron?* **(2)**

Ans. A cyclotron uses an alternating p.d. to give repeated *'positive accelerations'* to a beam of charged particles. The charged particles must, therefore, enter the field in the 'correct phase'. This is achieved in a cyclotron by

(i) Using a magnetic field to bend the path of the particles into a circle of radius r, where

$$\frac{mv^2}{r} = qvB \text{ or } r = \frac{mv}{qB}$$

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(ii) Adjusting the constant frequency (ν) (or time period) of the particles in the magnetic field to equal frequency of the applied a.c. e.m.f. The frequency, ν, is given by

$$\nu = \frac{v}{2\pi r} = \frac{vqB}{2\pi mv} = \frac{qB}{2\pi m}$$

We call this frequency as the *cyclotron frequency*. For a given beam of charged particles (given q and m) can be adjusted by adjusting the magnetic field strength. We adjust it to be equal to the frequency of (accelerating) alternating p.d. used and this helps the particles to continuously receive 'accelerating pushes' the correct phase.

[It is interesting to note that ν does not depend either on the speed (v) of the charged particles or the radius (r) of their circular path].

Q.59. *What are the primary functions of electric field and magnetic field in a cyclotron?*

Ans. In a cyclotron:

(i) The electric field is used to accelerate the charged particles.

(ii) The magnetic field is used to bend the path of the particles into a circle and to adjust the frequency of their rotation (in the circular path) to equal the frequency of the applied alternating e.m.f.

Q.60. *What is meant by cyclotron frequency?*

Ans. The *cyclotron frequency* is the frequency of rotation of the particles in their circular path.

$$\nu = \frac{qB}{2\pi m}$$

and equals the frequency of the applied (accelerating) alternating e.m.f.

Q.61. *With what frequency the particles orbit in their circular path in a cyclotron?*

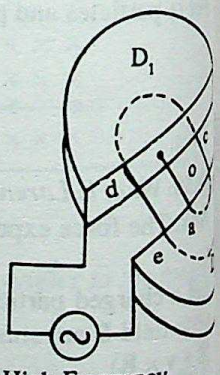
Ans. The frequency of the particles, known as their cyclotron frequency, is given by

$$\nu = \frac{qB}{2\pi m}.$$

Q.62. *Give the principle of a cyclotron. Draw a labelled diagram of cyclotron and explain, how a positively charged particle is accelerated in it?* **(3)**

Ans. Refer to the answer to question no. 58 for the principle of a cyclotron.

The labelled diagram of a cyclotron is given below:



When the charged particles enter the 'dee' of the cyclotron, their path gets bent, into a circle, by the magnetic field acting normally on them. The alternating e.m.f., present between the two 'dees', accelerates the charged particles wherever they cross the gap. As explained above, the correct adjustment of the 'cyclotron frequency', of the charged particles, ensures that the charged particles always enter the gap, between the 'dees', in the correct phase and are, therefore, continuously accelerated by it. Finally, the charged particles are made to leave the 'dees' and used for 'nuclear reactions', etc.

Q.63. *Describe the principle, construction and working of a cyclotron. Why is it not suitable for accelerating electrons? Give reasons.*

Ans. Refer to answer to question no. 62 above.

A cyclotron is not suitable for accelerating electrons. To see this, we notice that the cyclotron frequency is given by $\nu_c = \frac{qB}{2\pi m}$

Since, the mass of the electron is very low, the cyclotron frequency would be very high for electrons. Further, we notice that the radius r of the path of the charged particles, in a cyclotron, is given by

$$\frac{mv^2}{r} = qvB \Rightarrow r = \frac{mv}{qB}$$

The radius of the 'dees' needed would, thus, also be inconeniently small for acceleration of electrons. Because of those two practical difficulties, namely,

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(i) very high frequency value for the accelerating alternating p.d. and (ii) small radius of the 'dees' needed, the cyclotron is not suitable for accelerating electrons.

[**Note** : The value of ν_c would be nearly 2000 times less and the radius of the 'dees' would be 2000 times more for protons than for electrons. For protons, both the values turn out to be practically suitable].

Q.64. *Do we have any cyclotron motion in nature also?* **(2)**

Ans. Yes; the charged particles, present in cosmic rays, etc., when 'trapped' in the earth's magnetic field, can execute cyclotronic motions.

Q.65. *What is net force on a loop carrying current I and placed in a uniform magnetic field* **B***?* **(1)**

Ans. The net force is zero. [A current carrying loop is equivalent to a magnetic dipole of moment IA. The net force on a dipole, kept in a uniform field, in zero.]

Q.66. *A loop of irregular shape is made of a flexible wire and placed in an external magnetic field. What shape the loop acquires when a current is passed through it? Explain.* **(3)**

Ans. The loop would acquire a *circular shape* with the plane of the circle normal to the magnetic field. This is because, for a given perimeter, the circle encloses the maximum area in a plane. Hence, by acquiring the circular shape, the loop *maximizes* the flux (of the external magnetic field) linked with it. This position of maximum flux is also the position at which the induced e.m.f. (for small charges about this position) would be a minimum. It is, therefore, also the position of minimum potential energy. And, as we know, all natural systems, have a natural tendency to go over to the position of minimum potential energy.

Q.67. *A current carrying circular loop is located in a uniform magnetic field. If the loop is free to turn, what is the orientation of stable equilibrium?* **(1)**

Ans. The loop would orient itself with its plane normal to the field.

[The magnetic moment associated with the loop is *normal* to the plane of the loop. In an external magnetic field, the position of stable equilibrium is one in which the magnetic moment vector is parallel to the field.]

Q.68. *What is the magnetic moment associated with a coil of a turn, area of cross section* 10^{-4} m^2 *and carrying a current of 2A?* **(CBSE 1993) (2)**

Ans. We know that $\mu_m = n\,IA$

Here $n = 1, I = 2A, A = 10^{-4}\ m^2$

$\therefore \mu_m = 1 \times 2 \times 10^{-4}\ Am^2 = 2 \times 10^{-4}\ Am^2.$

Q.69. *Write an expression for the force experienced by a current carrying conductor placed in perpendicular external magnetic field.* **(1)**

Ans. Let a current carrying conductor, of length l, be kept normal to an external magnetic field B. If the current in the conductor is I, the force experienced by it.

$$\mathbf{F} = I(\boldsymbol{l} \times \mathbf{B})$$

In this case, therefore, the magnitude of the force is BI l.

Q.70. *A wire placed along x-axis of a cartesian co-ordinate system carries a current in the direction of positive x-axis. There exists a uniform magnetic field along the +ve z axis. What is direction of force on wire?* **(1)**

Ans. We have $\mathbf{F} = I(\boldsymbol{l} \times \mathbf{B})$

Here $\boldsymbol{l} = l\hat{i}$ and $\mathbf{B} = B\hat{k}$.

$\therefore \mathbf{F} = Il\,B(\hat{i} \times \hat{k}) = Il\,B(-\hat{j})$

$\therefore$ The force is along the negative direction of the y-axis.

Q.71. *Show that a current carrying conductor placed in a uniform magnetic field experiences a force given by*

$$\mathbf{F} = I(\boldsymbol{l} \times \mathbf{B}),$$ **(3)**

where l is the length of the conductor and I the current through it.

Ans. We know that the force **F** experienced by a charge q, moving with a velocity **v**, in an external magnetic field **B**, is given by $\mathbf{f} = q(\mathbf{v} \times \mathbf{B})$.

The total force on N such particles would be

$$\mathbf{F} = N\mathbf{f} = Nq(\mathbf{v} \times \mathbf{B})$$

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Now let a wire of length l, carrying a current I be present in an external magnetic field **B**. If there are charge carriers, per unit volume of the wire, each drifting with a speed v, we have

$$I = nqvA,$$

where q is the charge of each charge carrier and A is the area of cross section of the wire.

Now Al = volume of the wire.

$\therefore$ Total number, N, of charge carriers in the wire = $n A l$

Since each of these charge carriers is drifting with a velocity **v**, the total force on the wire (in an external magnetic field **B**) is $\mathbf{F} = Nq(\mathbf{v} \times \mathbf{B}) = n A l q (\mathbf{v} \times \mathbf{B})$

We can write $lv = vl$ as the direction of the l vector is taken to be along the direction of the current, which is the direction of drift of its (positive) charge carriers

$$\therefore \quad \mathbf{F} = nAqv (l \times \mathbf{B})$$

But nAqv = I, the current.

Hence, $$\mathbf{F} = I (l \times \mathbf{B}).$$

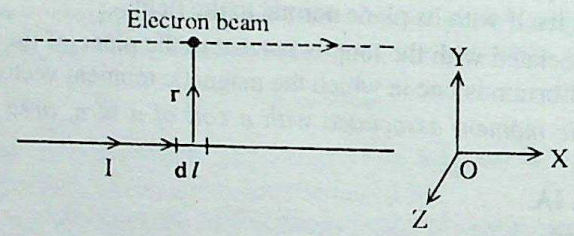
Q.72. *Write down the expression for the force on a current carrying conductor placed in magnetic field.*

(CBSE 1994 Comptt.)

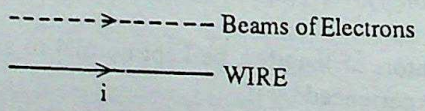
Ans. Let a current carrying conductor, carrying a current I, be placed in magnetic field **B**. The force $d\mathbf{F}$ on an element $\mathbf{dl}$ of the current carrying conductor is then given by

$$\mathbf{dF} = I (\mathbf{dl} \times \mathbf{B})$$

The total force F on the whole conductor is given by $\mathbf{F} = I \int_l (\mathbf{dl} \times \mathbf{B})$.



Q.73. *In the figure, is the beam of electrons attracted towards or repelled away from wire?*



Ans. The magnetic field due to the wire, at the position of the electron beam, is along the positive z-axis. $d\mathbf{l} = dl\,\hat{\mathbf{i}}$, $\mathbf{r} = r\hat{\mathbf{j}}$ so that $d\mathbf{l} \times \mathbf{r} = (dl)\, r\, (\hat{\mathbf{i}} \times \hat{\mathbf{j}}) = (dl\,(r)\,\hat{\mathbf{k}})$

The force on the electron beam is $\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$

v is along the $+\hat{\mathbf{i}}$ direction and **B** is along the $+\hat{\mathbf{k}}$ direction. Hence, $\mathbf{v} \times \mathbf{B}$ is along $\hat{\mathbf{i}} \times \hat{\mathbf{k}}$, *i.e.*, the $-\hat{\mathbf{j}}$ direction. However, q is also negative so that **F** is along the $+\hat{\mathbf{j}}$ direction. Thus, the electron beam is *repelled* by the current carrying wire. (alternatively)

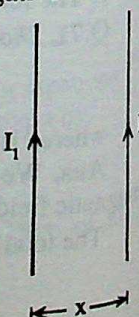
The electron beam, moving along the positive x-axis, is equal to a current along the negative x-axis. We thus, have two antiparallel currents and these, as we know, *repel* each other).

Q.74. *Write an expression for force per unit length between two long, straight parallel wires distance x apart and carrying current I_1 and I_2.*

(1)

Ans. The required expression, for the magnitude of the force, is $F = \dfrac{\mu_0}{2\pi} \dfrac{I_1 I_2}{x}$

The force is one of attraction if the currents are parallel to each other, and of repulsion, if the currents are antiparallel to each other.



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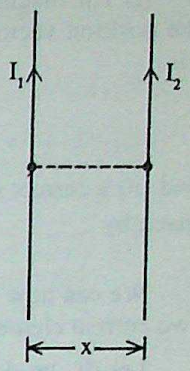
Q.75. *Obtain an expression for the force between two infinitely long straight parallel conductors carrying current in the same direction. Hence, define one ampere.* **(3)**



Ans. Let two long straight wires, carrying parallel currents I_1 and I_2, be kept a distance x apart in vacuum. The magnetic field due to the first wire, at the location of the second wire, is then

$$B_1 = \frac{\mu_0 I_1}{2\pi x}$$

This magnetic field is directed normal to the plane of the page and inwards. (By Biot-Savart's law).A unit length of wire 2, kept in this field, experiences a force

$$F_2 = I_2 B_1 \times 1 = \frac{\mu_0 I_1 I_2}{2\pi x}$$

From $\mathbf{F} = I(\boldsymbol{l} \times \mathbf{B})$, we see that this force is towards, wire 1, *i.e.*, the wire attract each other.

Similarly, wire 1 too experiences this much force but with the force directed towards wire 2.

Thus, in the given case, there is a force of attraction between the two wires and the magnitude of this force, per unit length of each wire, is

$$F = \frac{\mu_0 I_1 I_2}{2\pi x}$$

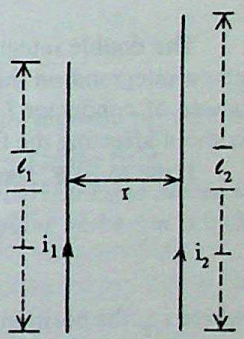
It follows that if $I_1 = I_2 = 1$ ampere and x = 1 metre, $F = \frac{\mu_0}{2\pi}$ newton $= 2 \times 10^{-7}$ newton. We, thus, define the *ampere* as follows :

The ampere is that constant current which when flowing through each two long straight (thin) parallel wires, kept one metre apart in vacuum, produces a force (of attraction) of 2×10^{-7} newton per metre of their length.

Q.76. *What is the effect of current flowing in the same direction in two long straight and parallel conductors? Give the definition of 'ampere' based on this effect.* **(CBSE 1994 Comptt.) (2)**

Ans. When two long straight and parallel conductors carrying currents in the same direction, they *attract* each other. This force of attraction is given by

$$F = \frac{\mu_0}{2\pi} \frac{I_1 I_2 l_1 l_2}{r^2}$$



If $I_1 = I_2 = 1$ ampere, $l_1 = l_2 = 1$ m and r = 1 m, we have

$$F = \frac{\mu_0}{2\pi} N = 2 \times 10^{-7} N$$

We use this result to define the ampere as follows:

The ampere is the strength of the constant current, which flowing through two long parallel conductors (of negligible cross section), placed 1 m apart in vacuum, produces between them a force of 2×10^{-7} N per metre of their length.

Q.77. *Derive the relation for the force per unit length between two infinitely long parallel straight wires carrying currents. Hence, define one ampere.* **(CBSE 1994) (3)**

Ans. Refer to answer to question no. 75.

Q.78. *Two current elements are placed a certain distance apart but not parallel to each other. Do they exert equal and opposite force on each other?* **(1)**

Ans. Yes; the forces exerted by the two, on each other, are equal and opposite, as per Newton's third law.

Q.79. *Obtain a general formula for the force between two current carrying conductors and use it to explain why "like currents" attract and "unlike currents" repel each other.* **(3)**

Ans. We know that

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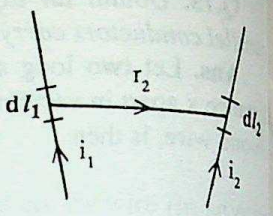
(i) The magnetic field **dB** due to a current element **dl** at a point P defined by the position vector **r** (w.r.t. the current element) is given by Biot-Savart's rule, *i.e.*,



$$\mathbf{dB} = \frac{\mu_0}{4\pi} I \frac{\mathbf{dl} \times \mathbf{r}}{r^3}$$

and (ii) a current element d*l* present in a magnetic field **B** experiences a force **dF** given by

$$\mathbf{dF} = I\,(\mathbf{dl} \times \mathbf{B})$$

We can now use these results to get a general formula for the force between two current elements d*l*. and $\mathbf{dl}_2$ carrying currents I. and I_2 respectively.

Let $\mathbf{dl}_2$ be defined by the position vector $\mathbf{r}_{21}$ with respect to $\mathbf{dl}_1$. The field $\mathbf{dB}_1$ at $\mathbf{dl}_2$ due to the current element $\mathbf{dl}_1$ is then given by

$$\mathbf{dB}_1 = \frac{\mu_0}{4\pi} I_1 \frac{\mathbf{dl}_1 \times \mathbf{r}_{21}}{r_{21}^3}.$$

Because of this field, the current element $\mathbf{dl}_2$ experiences a force. This force, $d\mathbf{F}_{21}$, is given by

$$\begin{aligned} \mathbf{dF}_{21} &= I_2 \mathbf{dl}_2 \times \mathbf{dB}_1 \\ &= I_2\, \mathbf{dl}_2 \times \left[\left(\frac{\mu_0}{4\pi} I_1 \right) \frac{\mathbf{dl}_1 \times \mathbf{r}_{21}}{r_{21}^3} \right] \\ &= \frac{\mu_0}{4\pi} I_1 I_2 \frac{\mathbf{dl}_2 \times (\mathbf{dl}_1 \times \mathbf{r}_{21})}{r_{21}^3} \end{aligned}$$

The complete force on the conductor l_2 due to the whole of conductor l_1 is then given by

$$\mathbf{F}_{21} = \frac{\mu_0}{4\pi} I_1 I_2 \int_{l_1} \int_{l_2} \frac{\mathbf{dl}_2 \times (\mathbf{dl}_2 \times \mathbf{r}_{21})}{r_{21}^3}$$

The double integration here implies that the integration is to be carried out in two steps : first integrate the given integrand on the whole of conductor l_2 and get the integration result. Next integrate this *result* over the whole of conductor l_1 to get the final result for the force. The order of integration can, however, be changed without affecting the final result.

If the force $\mathbf{F}_{12}$ on conductor l_1 due to the conductor l_2 is to be written, we will similarly have

$$F_{12} = \frac{\mu_0}{4\pi} i_2 i_1 \int_{l_2} \int_{l_1} \frac{\mathbf{dl}_1 \times \mathbf{dl}_2 \times \mathbf{r}_{12}}{r_{12}^3}.$$

where r_{12}, the position vector of element $\mathbf{dl}_1$ w.r.t. element $\mathbf{dl}_2$, is clearly $-\mathbf{r}_{21}$. It then follows that

$$\mathbf{F}_{12} = -\mathbf{F}_{21}$$

as per the requirements of Newton's third law of action and reaction.

Q.80. *Explain why two straight parallel metallic wires, carrying currents in opposite directions, repel each other.* **(CBSE 1994) (3**

Ans. Let AB and CD denote the two parallel wires carrying oppositely directed currents I_1 and I_2. We can then regard each wire as situated in the magnetic field of the other current carrying wire.

Choose the axis, as shown. We then have

B_1 = magnetic field due to wire AB at a point on wire CD, is given by $\mathbf{B}_1 = \frac{\mu_0}{4\pi} I_1 \frac{\mathbf{dl}_1 \times \mathbf{r}_{12}}{|\mathbf{r}_{12}|^3}$

Since $\mathbf{dl}_1$ is along $\hat{\mathbf{j}}$ and $\mathbf{r}_{12}$ along $\hat{\mathbf{i}}$, we see that $\mathbf{B}_1$ is along $-\hat{k}$, *i.e.*, perpendicular to the plane of the page and directed inwards.

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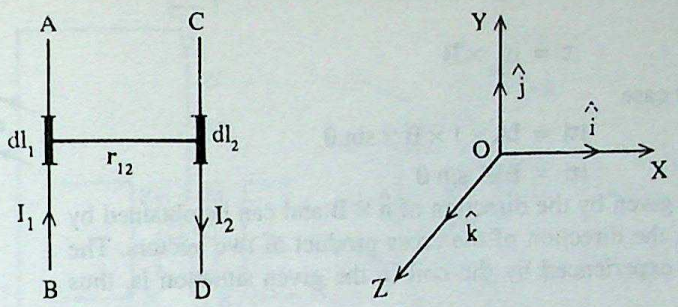

Now consider the force on an element dl_2 of wire CD the force F_2 is given by

$$\mathbf{F_2} = \mathbf{I_2}\,(d\mathbf{l_2} \times \mathbf{B_1})$$

since $d\mathbf{l_2}$ is along $-\hat{j}$ and $\mathbf{B_1}$ is along $-\hat{k}$, $\mathbf{F_2}$ is along $(-\hat{j}) \times (-\hat{k})$ *i.e.* along $\hat{i}$.

It is, thus, seen that the wire CD moves away from wire AB, *i.e.*, gets repelled. A similar argument shows that the force on wire AB is along $-\hat{i}$, *i.e.*, away from wire CD. The two wires, therefore, repel each other.

Q.81. *Show that a rectangular coil carrying current placed in a uniform magnetic field experiences a torque.* **(3)**

Ans. Let a rectangular coil of length l and width b, be kept in a uniform external magnetic field **B**. When the coil carries a current I, it is equivalent to a magnetic dipole of moment μ_m, where

$$\mu_m = I\,(l\,b)\,\hat{n}$$

Here $\hat{n}$ is a unit vector, normal to the plane of the coil and in the sense of advance of a right handed screw rotated along the sense of flow of current through the coil.

Now a magnetic dipole, of moment μ_m, experiences a torque τ is a uniform magnetic field **B**, where

$$\tau = \mu_m \times \mathbf{B}$$

The torque experienced by the rectangular coil is, therefore,

$$\tau = I A\hat{n} \times \mathbf{B}.$$

where A (= l b) is the area of the coil. The torque tends to adjust the (equivalent) magnetic moment μ_m parallel to a field. The torque, therefore, tends to orient the rectangular coil so that its plane is normal to the field.

Q.82. *Derive an expression for the torque on a rectangular coil of area A carrying a current I and placed in a magnetic field B. The angle between the direction of B and vector perpendicular to the plane of the coil is* θ. **(3)**

Ans. Refer to answer to Q. No. 81 above. As, we have seen, the torque τ is given by

$$\tau = IA\,\hat{n} \times \mathbf{B}$$

Here $|\hat{n} \times \mathbf{B}| = 1 \times B \times \sin\theta = B \sin\theta$

$$\therefore \quad |\tau| = IAB \sin\theta,$$

This torque, as we have seen, tends to adjust the coil so that its plane is normal to the field direction.

Q.83. *Derive the expression for the torque on a rectangular coil of area A, carrying a current I, placed in a magnetic field B. The angle between the direction of B and the vector perpendicular to the plane of the coil is* θ. **(CBSE 1993) (3)**

OR

A moving coil galvanometer consists of a rectangular coil of N turns, each of area A, suspended in a radial magnetic field of flux density B. Derive the expression for the torque on the coil when a current I passes through it. Draw a suitable labelled diagram. **(CBSE 1993 Comptt.) (3)**

Ans. We know that we can associate an equivalent magnetic dipole moment, μ_m, with a current carrying coil. μ_m is known to be given by $\mu_m = IA\,\hat{n}$, where $\hat{n}$ is a unit vector perpendicular to the plane of the coil and

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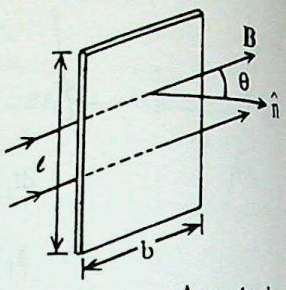
related to the sense of current flow in it by 'right hand screw' rule. Now when a dipole of moment μ_m is present in a magnetic field B, it experiences a torque τ, where

$$\tau = \mu_m \times \mathbf{B}$$



A = ℓ × b

Hence, in the present case

$$\therefore \quad |\tau| = IA \times 1 \times B \times \sin\theta$$

$$\therefore \quad |\tau| = BIA \sin\theta$$

The direction of τ is given by the direction of $\hat{n} \times \mathbf{B}$ and can be obtained by the usual rule for finding the direction of the cross product of two vectors. The magnitude of the torque experienced by the coil in the given situation is, thus BIA sin θ.

Q.84. *Explain with the help of a labelled diagram, the underlying principle, construction and working of a cyclotron.* **(CBSE 1997)**

Ans. See answer to question no. 62.

Q.85. *Derive mathematical expression for the force per unit length acting on each of the two straight parallel metallic conductors carrying current in the same direction and kept near each other. Why do such current carrying conductors attract each other?* **(CBSE 1998)**

Ans. See answers to questions 75 and 79.

Q.86. *Derive a mathematical expression for the force acting on a current carrying straight conductor kept in a magnetic field. State the rule used to determine the direction of this force.*

(CBSE 1998)

Ans. See answer to questions 72 for 1st part. The direction of force F can be determined by using Fleming's left hand rule, which states that if we stretch the thumb, the first finger and the central finger of our left hand mutually perpendicular to each other and if the first finger point in the direction of the magnetic field and the central finger points in the direction of current then the thumb points in the direction of force on the conductor carrying current.

Q.87. *Explain the principle of a moving coil galvanometer.*

Ans. The moving coil galvanometer is based on the following concepts:

(i) A current carrying rectangular coil is equivalent to a magnetic dipole of moment $\mu_m = IA\,\hat{n}$; where I = current through the coil, A = area of the coil and $\hat{n}$ = a unit vector normal to the plane of the coil in the sense of advance of a right handed screw rotated along the sense of the current flowing through the coil.

(ii) A magnetic dipole, when kept in a uniform magnetic field **B**, experiences a torque τ, where

$$\tau = \mu_m \times \mathbf{B}$$

(iii) The torque τ has a magnitude μ_m B or IAB when the field **B** is always normal to μ_m. (This is achieved by using a radial magneic field).

(iv) The deflection, θ, of the coil, from its equilibrium position, under these conditions, is directly proportional to the current flowing through it. This enables us to have a *linear scale* in a moving coil galvanometer.

Q.88. *Describe the principle construction and working of a moving coil galvanometer. Show that for such an instrument the current passing through the coil is directly proportional to the deflection produced.*

Ans. Principle : A current carrying conductor placed in a magnetic field experiences a force. The couple acting on a coil of n turns, cross-sectional area A placed in a *radial magnetic field* B is nABI, where I is the current in the coil.

Construction : Fig. below (a) and (b) shows the "front" and "three-dimensional" view of a *De Arsonval's* moving coil, suspension type galvanometer. PQRS is the coil suspended in between the pole pieces N and S of a eleetromagnet, W is a suspension wire of *phosphor-bronze.* M is a mirror attached to the suspension wire. It is used to determine the deflection of coil using *lamp and scale* arrangement. T is a torsion-head. S_1 is a torsion-

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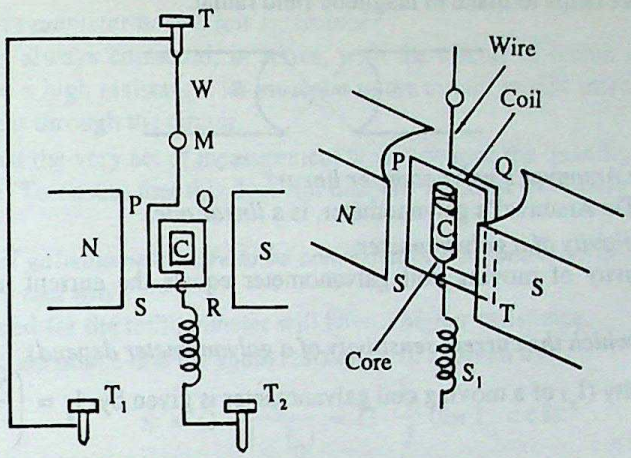
less spring attached to one end of coil PQRS. C is the *soft-iron* core. T_1 and T_2 represent the galvanometer terminals.



"FRONT VIEW"

Working : When a current I passes through the galvanometer, it experiences a deflecing couple nABi. Due to this the coil turns through an angle θ; producing a twist in the suspension wire. A *restoring couple* comes into play due to elasticity of suspension wire. Let c be the *torsional rigidity* (*i.e.*, couple required per unit twist) of suspension wire. The restoring couple is cθ. In equilibrium

Deflecting couple = Restoring couple

or $$nABI = c\theta \quad \therefore I = c\,\theta/n\,AB = \frac{\theta}{I_s} \qquad ...(i)$$

where $I_s = \frac{nAB}{C}$ I_s is current required to produce unit twist and is known as the *current sensitivity* of the galvanometer.

It is seen that $I \propto \theta$. Hence, the current passing through the coil, and the deflection produced, are proportional to each other.

Q.89. *Why is the coil of a moving coil galvanometer wound on an aluminium frame?* **(1)**

Ans. The coil of a moving coil galvanometer is wound on an aluminium frame because:

(i) Aluminium, being a very light metal, does not add significantly to the inertia of the moving coil.

(ii) Aluminium, being a metal, has induced eddy currents set up in it (due to the motion of the coil in a magnetic field). These eddy currents help to damp the oscillations of the coil and make its action *'dead beat'*

Q.90. *Why is phosphor bronze alloy preferred for the suspension wire of a moving coil galvanometer?* **(1)**

Ans. We prefer a suspension wire made of phosphor bronze because of the excellent *linear elastic behaviour* of this alloy. (The restoring elastic torque, set up in it, is directly proportional to its angle of twist, even for large values of this).

Q.91. Why is the suspension taken in the form of a spring in a moving coil galvanometer? **(1)**

Ans. The use of the *spring* enables us to have an easily portable and compact instrument.

Q.92. *What is a radial magnetic field?* **(1)**

Ans. A radial magnetic field is a magnetic field, that is, normal to the plane of the coil for all positions of the coil.

Q.93. Why we desire a radial magnetic field in a moving coil galvenometer? **(1)**

Ans. We desire a radial magnetic field in a moving coil galvanometer so as to have a linear (directly proportional) relation between the deflection of the coil and the current flowing through it.

Q.94. How is the magnetic field made radial in a moving coil galvanometer? **(2)**

Ans. The magnetic field is made radial by using concave pole pieces. The use of a soft iron cylinder, kept within the plane of the coil, also helps.

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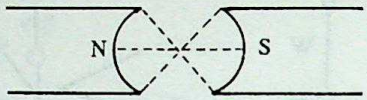
Q.95. *What is the role of soft iron cylinder in a moving coil galvanometer?*

Ans. The soft iron cylinder helps to make to magnetic field radial. (2



Q.96. *Is the scale of a De Arsonval's galvanometer linear?*

Ans. Yes; the scale, of a De Arsonval's galvanometer, is a *linear one.* (1

Q.97. *Define current sensitivity of a galvanometer.* (1

Ans. The *current sensitivity* of moving coil galvanometer equals the current needed to produce a unit deflection in it.

Q.98. *List the factors on which the current sensitivity of a galvanometer depends.* **(CBSE 1993)** (1

Ans. The current sensitivity (I_s) of a moving coil galvanometer is given by $I_s = \left(\frac{NAB}{C}\right)$

It, thus, depends on :

(i) The torsional constant c of the suspension wire.

(ii) The number, of turns N, of the coil.

(iii) The area, A of each turn of the coil.

(iv) The magnetic field, B, in which the coil rotates.

Q.99. *How one can increase the current sensitivity of a moving coil galvanometer?* (1

Ans. One can increase the current sensitivity of a moving coil galvanometer by

(i) decreasing c, the torsional constant of the suspension wire.

(ii) increasing N (= no. of turns of the coil),

B (= magnetic field in which the coil moves).

Q.100. *Can we use a galvanometer for the measurement of an unknown current.?* (1

Ans. Yes; we will, however, need to calibrate it. Also the current, to be measured, must lie within the permissible maximum current that can flow through the given galvanometer.

Q.101. *Can a De Arsonval's moving coil galvanometer measure an alternating current?* (1

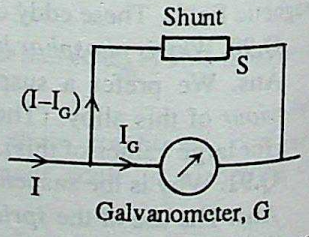
Ans. No; the De Arsonval's galvanometer cannot measure an alternating current. It will show 'zero deflection' when such a current flows through it.

Q.102. *What is a shunt? Why is it used in the galvanometer?* (2

Ans. A *shunt* is a (very) low resistance coil connected, in parallel, across the coil of a moving coil galvanometer.

A *shunt* helps us to increase the range (of current) over which a given galvanometer can be used. We can use a shunt (of suitable value (say S)) to increase the range of a galvanometer (of resistance G, say) from its (original) value of I_G, to a given desired value, say, I. The required value of S, is given by

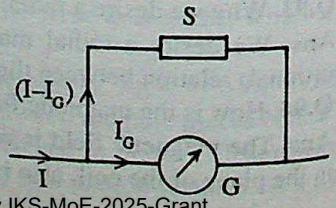
$$S = \frac{I_G}{(I - I_G)} G$$



Q.103. *How can we convert a moving coil galvanometer into an ammeter?* (3

Ans. We can convert a given galvanometer (of resistance G and maximum permissible current, I_G) into an ammeter of range (0 –I) ampere by connecting a shunt of resistance, S, in parallel with the galvanometer coil. The value of, S, is given by

$$S \cdot (I - I_G) = G.I_G \quad \text{or} \quad S = G \cdot \frac{I_G}{(I - I_G)}$$



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Q.104. *What should be the resistance of an ideal ammeter?* **(1)**

Ans. The resistance of an ideal ammeter should be *zero.*

Q.105. *Why should an ammeter have a low resistance?* **(2)**

Ans. An ammeter is always conneced, in series, with the circuit in which it is to be used for measuring current. If it were to have a high resistance, its presence in the circuit would increase the circuit resistance. This would decrease the current through the circuit.

This would imply that the very act of measurement would change the quantity that was to be measured. This is certainly not desirable. To ensure that this does not happen, we must have only a very low resistance value of the ammeter.

Q.106. *Two identical galvanometers are to be converted into an ammeter and a milliammeter. Whose shunt will have more resistance and why?* **(2)**

Ans. The shunt needed for the milliammeter will have a *higher* resistance.

The understand this, we notice that the shunt resistance, S, is given by

$$S = G \cdot \frac{I_G}{(I - I_G)} \approx G \cdot \frac{I_G}{I} \text{ (for } I_G << I).$$

Thus, more the value of I (*i.e.*, more the range up to which the galvanometer is to be converted, the less is the value of S. Since the range is definitely more for an ammeter (than for a milliameter), we will need a higher resistance for a milliammeter.

Q.107. *What is the resistance of shunt requied to increase the range of a galvanometer by n times? What is the resistance of converted ammeter?* **(2)**

Ans. We have $S = G \cdot \frac{I_G}{(I - I_G)}$.

Here $I = nI_G$. Hence, $S = G \cdot \frac{I_G}{(n-1)\, I_G} = \frac{G}{(n-1)}$

Thus, the required shunt resistance is $\frac{1}{n-1}$ times the galvanometer resistance. The equivalent resistance, of the converted ammeter, is given by

$$\frac{1}{R} = \frac{1}{S} + \frac{1}{G} = \frac{n-1}{G} + \frac{1}{G} = \frac{n-1+1}{G} = \frac{n}{G}$$

Thus, the equivalent resistance of the converted ammeter is $\left(\frac{1}{n}\right)$th of the galvanometer resistance.

Q.108. *What should be the resistance of an ideal voltmeter?* **(1)**

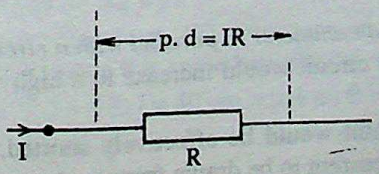
Ans. The resistance of an ideal voltmeter should be infinite.

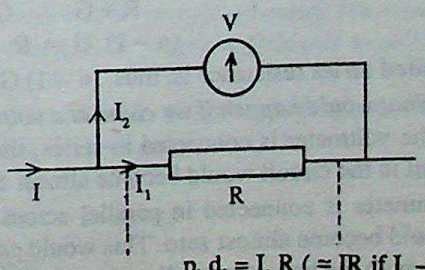
Q.109. *Name an ideal voltmeter.* **(1)**

Ans. An electronic voltmeter *or* an electrostatic voltmeter can serve as an ideal voltmeter.

Q.110. *Why should a voltmeter have a high resistance?* **(2)**

Ans. A voltmeter should have a high resistance because it is always connected, in parallel, across the points between which the p.d. is to be measured. The introduction of the voltmeter thus provides *an alternative path* to





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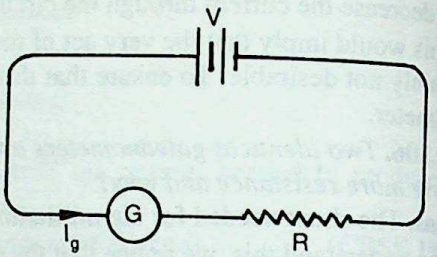
the current, flowing through the device, across which the p.d. is to be measured. The more the resistance of the voltmeter, the less would be the current through it. Hence, there would then be very little change in the current originally flowing through the device. For an infinite resistance voltmeter, this charge would be zero and, that is what ideally required. We, therefore, want the voltmeter to have as high a resistance as possible.

Q.111. *How can a galvanometer of resistance G be converted into a voltmeter to read a maximum potential difference V volts? Support your answer with related mathematical expression.* **(CBSE 1998) (2)**



Ans. To convert a galvanometer of resistance G into a voltmeter to read a maximum p.d. V, we need to connect a resistance R in series with it. The resistance R should be such that it sends a current IG only through the galvanometer when a p.d. V is applied across it.

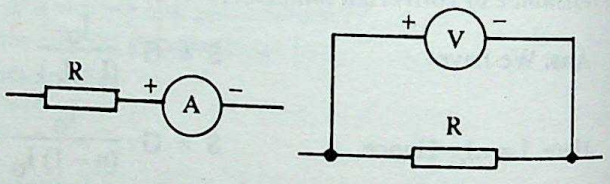
$$I_G = \frac{V}{R+G} \Rightarrow R = \frac{V}{I_G} - G$$

Q.112. *Out of an ammeter and a voltmeter, which of the two has a higher resistance and why?* **(CBSE 1994) (2)**

Ans. The voltmeter has a higher resistance than the ammeter.

The reason is as follows :

The voltmeter is always connected *in parallel* to the two terminals between which the p.d. is to be measured. It must not draw any current through itself to keep the p.d. to be measured unchanged. Hence, the resistance of an ideal voltmeter must be infinite.



The ammeter is always connected in *series* with the branch of the circuit through which the current flowing is to be measured. To keep this current unchanged, the ammeter must not cause any change in the resistance of that branch. *Hence, the resistance of an ideal ammeter must be zero.*

Q.113. *A galvanometer of resistance G has a maximum safe p.d. of V_{max}. What resistance be connected in series with it so that it becomes a voltmeter of range nV_{max}?* **(3)**

Ans. The safe p.d. = V_{max}, Resistance = G

$\therefore$ Safe current through the galvanomter $I_G = \dfrac{V_{max}}{G}$

Let R be the required (series) resistance, needed with a p.d. of nV_{max}. The current through the galvanometer should still be I_G. Hence,

$$I_G = \frac{nV_{max}}{R+G}$$

$\therefore$ $$\frac{nV_{max}}{R+G} = \frac{V_{max}}{G} \Rightarrow nG = R+G$$

or $$(n-1)\,G = R$$

The required series resistance is, thus, (n —1) G.

Q.114. *What would happen if we connect a voltmeter in series or an ammeter in parallel with a circuit?* **(2)**

Ans. If the voltmeter is connected in series, the resistance of the circuit would increase to a high value so that the current in the circuit would become almost zero.

If the ammeter is connected in parallel across a circuit, the circuit would be effectively shorted, *i.e.*, its resistance would become almost zero. This would cause a very heavy current to be drawn from the battery which could damage both the battery as well as the ammeter.

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Q.115. *What is a multimeter? What is its advantage?* **(2)**

Ans. A *multimeter* is a multipurpose meter that can serve as an ammeter or a voltmeter, of different ranges. It can also be used as an *ohm-meter, i.e.,* a direct resistance value reading meter. The multimeter also has provision for reading alternating voltages and currents. Some multimeters also have special leads for reading high voltages or heavy currents.

The multimeter, because of its compactness and versatility, is an essential requirement of all Electronics and Physics laboratories.

Q.116. *What is an 'AVO' meter?* **(1)**

Ans. The 'AVO' meter is another name for the multimeter. The letters A, V and O here stand for the ampere, volt and ohm. The instrument is, thus, capable of measuring currents, voltages and resistances.

SOLVED NUMERICAL PROBLEMS ON UNIT – IV

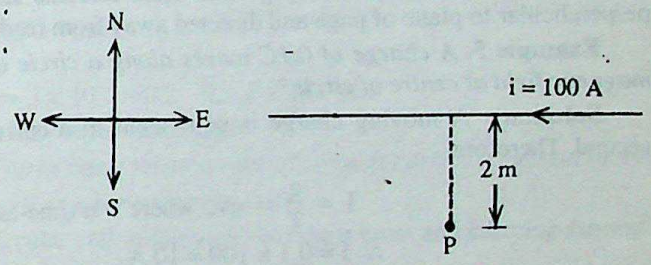
Example 1. *A horizontal overhead power cable carries a current of 100 A from east to west. What is the magnitude and direction of magnetic field at a point 2 m below the cable?*

Solution : Consider overhead cable as an infinite straight wire. The magnetic field (B) at a point distance a from it

$$B = \frac{\mu_0 I}{2\pi a}$$

Given $I = 100$ A, $a = 2$ m

$$\therefore \quad B = \frac{4\pi \times 10^{-7} \times 10^2}{2\pi \times 2} T = 10^{-5} \text{ T.}$$



The direction of magnetic field is given by the right-hand screw rule. From fig. alongside it is clear that direction of **B** is southwards.

Example 2. *A straight solenoid has a length of 80 cm and a mean diameter of 2 cm. There are 4 layers each having 1000 turns. The solenoid carries a current of 4 A. What is magnetic field at the centre of solenoid?*

Solution : The magnetic field (B) due to a straight solenoid is $B = \frac{\mu_0 NI}{L}$.

where N = Total number of turns, L = Length of solenoid.

Since there are four layers each having 1000 turns;

$$N = 4 \times 1000 = 4000; \; L = 80 \text{ cm} = 0.8 \text{ m}; \; I = 4\text{A}$$

$$\therefore B = \frac{4\pi \times 10^{-7} \times 4 \times 10^3 \times 4}{0.8} T = 8\pi \times 10^{-3} \text{ T.}$$

Example 3. *A straight wire 40 cm long is placed near the centre of a straight solenoid. The wire carries a current of 5 A and makes an angle of 60° with the axis of the solenoid. The magnetic field due to solenoid is 0.2 T. What is force on the wire ?*

Solution : The force (F) on a wire of length l carrying a current (I), placed in a magnetic field (B) is $F = BIl \sin\theta$, where θ is angle between the wire and the magnetic field. Given

$B = 0.2$ T; $I = 5$A; $l = 40$ cm $= 0.4$ m; $\theta = \pi/3$

$$\therefore \quad F = 0.2 \times 5 \times 0.4 \sin 60° \text{ N}$$

$$= 1 \times 0.4 \times \frac{\sqrt{3}}{2} \approx 0.35 \text{ N.}$$

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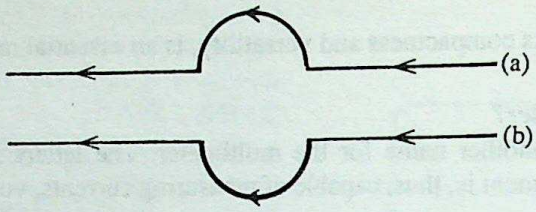
Example 4. *A straight wire carrying a current of 20 A is bent into a semicircular arc of radius 4 cm as shown in fig. (a) below. What is the magnitude and direction of magnetic field at the centre of the arc? Would your answer change if semicircular arc is as shown in fig. (b)?*



Solution : The magnetic field (B) at centre of a semicircular arc is $B = \frac{1}{2}\left[\frac{\mu_0 I}{2r}\right]$, where r is radius of semi-circle. Given $I = 20$ A; $r = 4$ cm $= 4 \times 10^{-2}$ m

$$\therefore \quad B = \frac{4\pi \times 10^{-7} \times 20}{4 \times 4 \times 10^{-2}} \text{ T} = 5\pi \times 10^{-5} \text{ T}$$

The direction of magnetic field is given by right-hand screw rule. In fig. (a) above **B** is perpendicular to plane of page and directed towards reader, *i.e.*

In fig. (b) magnitude of magnitude field remains same but its direction *reverses*. In other words, B is perpendicular to plane of page and directed away from reader.

Example 5. *A charge of 0.1C moves along a circle of radius of 2 cm at a frequency of 100 Hz. What is magnetic field at centre of circle?*

Solution : A moving charge is equivalent to a current. By definition current (I) is charge flowing per second. Therefore,

$$I = \frac{q}{T} = qv, \text{ where T is time-taken to complete one circle}$$

$$\therefore \ I = 0.1 \times 100 = 10 \text{ A}$$

The magnetic field at centre of circle is $B = \frac{\mu_0 I}{2r}$,

where $r = 2$ cm $= 2 \times 10^{-2}$ m is the radius of the circle.

$$\therefore \quad B = \frac{4\pi \times 10^{-7} \times 10}{2 \times 2 \times 10^{-2}} \text{T} = \pi \times 10^{-4} \text{ T} = 3.14 \times 10^{-4} \text{ T}.$$

Example 6. *(i) An electron of kinetic energy 25 keV moves perpendicular to the direction of a uniform magnetic field of 0.2 millitesta. Calculate the time period of rotation of the electron in the magnetic field.*

(ii) An electron in an atom revolves around the nucleus in an orbit of radius 0.53 Å. Calculate the equivalent magnetic moment, if the frequency of revolution of electron is 6.8×10^9 MHz. **(CBSE 1997 Compt.)** **(CBSE 1998)**

Solution: (i) K.E. $= 25$ keV $= 25 \times 1.6 \times 10^{-16}$ J, $B = 0.2 \times 10^{-3}$ T

$$\text{K.E} = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{\frac{2.\text{K.E.}}{m}} = \sqrt{\frac{2 \times 25 \times 1.6 \times 10^{-16}}{9.1 \times 10^{-31}}} = 9.3 \times 10^7 \text{ m/s}$$

Also,
$$r = \frac{mv}{Be} = \frac{9.1 \times 10^{-31} \times 9.3 \times 10^7}{0.2 \times 10^{-3} \times 1.6 \times 10^{-19}} = 2.64 \text{ m}.$$

$$T = \frac{2\pi r}{v} = \frac{2 \times 3.14 \times 2.64}{9.3 \times 10^7} = 1.78 \times 10^{-7} \text{ s}.$$

(ii)
$$r = 0.53 \text{ Å} = 0.53 \times 10^{-10} \text{ m},$$
$$f = 6.8 \times 10^9 \text{ MHz} = 6.8 \times 10^{15} \text{ Hz}$$

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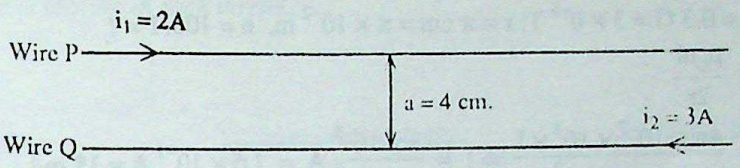
$$M = IA = I.\pi r^2 = eI\pi r^2 \quad (\because I = ef)$$
$$= 1.6 \times 10^{-19} \times 6.8 \times 10^{15} \times 3.14 \times (0.53 \times 10^{-10})^2$$
$$= 9.59 \times 10^{-24}\ Am^2 = \mathbf{9.6 \times 10^{-24}\ Am^2}.$$

Example 7. *Two straight wires P and Q of length 20 m and 30 m respectively carrying currents of 2A and 3A respectively in opposite directions; are parallel to one another at a distance of 4 cm. What is force on 20 cm long section of wire Q located near centre of wire?*



Solution : Since length of wires is large as compared to their distance apart, we can regard each as an infinite straight wire.

The force per unit length (f) between the two wires is $f = \dfrac{\mu_0 I_1 I_2}{2\pi a}$

Given $I_1 = 2A$; $I_2 = 3A$; $a = 4\ cm = 4 \times 10^{-2}\ m$

$$\therefore \quad f = \frac{4\pi \times 10^{-7} \times 2 \times 3}{2\pi \times 4 \times 10^{-2}}\ 'Nm^{-1} = 3 \times 10^{-5}\ Nm^{-1}.$$

F = force on 20 cm length of wire Q $= 3 \times 10^{-5} \times 0.2\ \ N = \mathbf{6 \times 10^{-6}\ N}$.

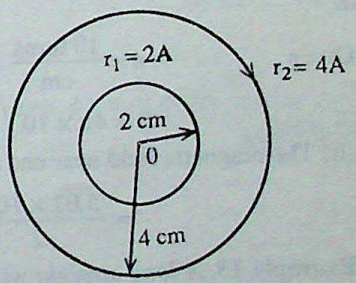
Since wires carry currents in opposite directions they repel one another.

Example 8. *A circular coil having a number of turns has a mean radius of 5 cm. It carries a current of 5 A. The magnetic field at centre of coil is $\pi \times 10^{-4}$ T what is number of turn in coil?*

Solution : The magnetic field (B) at centre of circular coil of raidus (r) having n turns and carrying current I is $B = \dfrac{\mu_0 nI}{2r}$. Given $B = \pi \times 10^{-4}$ T; I = 5A, r = 5 cm $= 5 \times 10^{-2}$ m

$$\therefore\ \pi \times 10^{-4} = \frac{4\pi \times 10^{-7} \times n \times 5}{2 \times 5 \times 10^{-2}} \text{ or } n = \frac{10^{-4}}{2 \times 10^{-5}} = \mathbf{5\ turns}.$$

Example 9. *Two concentric circles of radius 2 cm and 4 cm respectively carry current of 2A and 4A in clockwise direction. What is net magnetic field at the centre? If the direction of current in inner circle is reversed, what is net magnetic field at the centre?*



Solution : Fig. below shows the two cirlces. Let r_1 and r_2 be radius of inner and outer circle respectively.

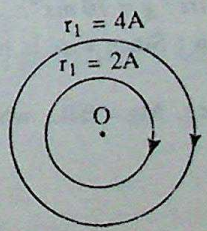
Given $r_1 = 2\ cm = 2 \times 10^{-2}$ m and $r_2 = 4 \times 10^{-2}$ m.

B_1 = magnetic field at centre O due to inner circle

$$= \frac{4\pi \times 10^{-7} \times 2}{2 \times 2 \times 10^{-2}}\ T = 2\pi \times 10^{-5}\ T$$

and B_2 = magnetic field at centre O due to outer circle

$$= \frac{4\pi \times 10^{-7} \times 4}{2 \times 4 \times 10^{-2}}\ T = 2\pi \times 10^{-5}\ T.$$



According to right-hand screw rule, direction of $\mathbf{B}_1$ and $\mathbf{B}_2$ is perpendicular to plane of page and directed away from reader. Since $\mathbf{B}_1$ and $\mathbf{B}_2$ are in same direction, the net magnetic field **B** is

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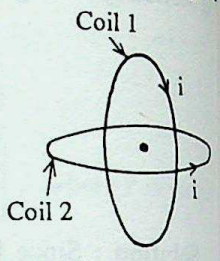
$$B = (2\pi \times 10^{-5} + 2\pi \times 10^{-5}) T; = 4\pi \times 10^{-5} \text{ T}$$

Fig. alongside shows situation when current in inner circle is reversed.

Now $\mathbf{B}_1$ and $\mathbf{B}_2$ have same magnitude but opposite directions. Hence, *net field* at centre O is *zero.*

Example 10. *A circular coil of mean radius π cm havings 100 turns is placed in a vertical plane. The n field at centre of coil is zero. If horizontal component of earth's magnetic field is 0.3 G, what is current in coil?*

Solution : Since net magnetic field at centre of coil is zero, the magnetic field due to coil must be equal magnitude and opposite in direction to earth's magnetic field.



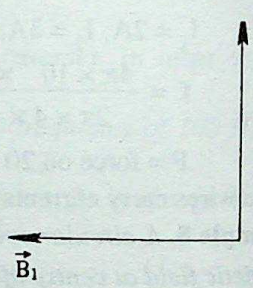
In other words $B = 0.3\ G = 3 \times 0^{-5}$ T; $r = \pi$ cm $= \pi \times 10^{-2}$ m, $n = 100$, $I = ?$

We know $B = \dfrac{\mu_0 nI}{2r}$

$$\therefore \quad 3 \times 10^{-5} = \frac{4\pi \times 10^{-7} \times 10^2 \times I}{2 \times \pi \times 10^{-2}} \Rightarrow I = \frac{3 \times 10^{-5}}{2 \times 10^{-3}} A = 1.5 \times 10^{-2} A = \mathbf{15\ mA}.$$

Example 11. *Two identical circular coils each of radius 10 cm are arranged concentrically with their plane perpendicular to one another as shown in fig. below. If current in each coil is 10 A, what is net magnetic field at the common centre O?*

Solution : The magnetic field at common centre O due to each coil has same magnitude. The two fields are mutually perpendicular as shown in fig. alongside.



$$|\mathbf{B}_1| = |\mathbf{B}_2| = \frac{\mu_0 I}{2r} = \frac{4\pi \times 10^{-7} \times 10}{2 \times 10^{-1}} \text{ T} = \mathbf{2\pi \times 10^{-5}\ T}$$

The net magnetic field B is

$$B = \sqrt{B_1^{\,2} + B_2^{\,2}} = \sqrt{2}\ B_1 = \mathbf{2\sqrt{2}\ \pi \times 10^{-5}\ T}.$$

B makes an angle of 45° with the plane of either coil.

Example 12. *A long straight solenoid having 10 turn per cm has a length of 60 cm. It carries a current of 4A. What is the magnetic field at a point on the axis.*

(i) in the interior (ii) at one end of solenoid ?

Solution : (i) The magnetic field (B) at centre of solenoid is $B = \mu_0\ n\ I$, where n = number of turns per unit length

Given $\quad n = \dfrac{10 \text{ turns}}{\text{cm}} = 10 \times 10^2$ turns per meter, $I = 4A$

$$\therefore \quad B = 4\pi \times 10^{-7} \times 10^3 \times 4 = 16\pi \times 10^{-4}\ T = 50.24 \times 10^{-4}\ T = \mathbf{5.02 \times 10^{-3}\ T}$$

(ii) The magnetic field near end equals *half* the magnetic field at centre

$$= \frac{5.02 \times 10^{-3}}{2}\ T = \mathbf{2.515 \times 10^{-3}\ T}.$$

Example 13. *A long straight wire having a mass of 0.6 g/cm is held in equilibrium in a horizontal position in the gravity of earth without any support by applying a perpendicular magnetic field of 0.1 T. What is current in wire? $g = 10\ ms^{-2}$.*

Solution : Since wire is in equilibrium; the weight of wire is balanced by the force on it due to magnetic field.

Therefore, $Mg = BIL$, where M and L denote mass and length of wire

$$\therefore \quad I = \left(\frac{M}{L}\right)\frac{g}{B}$$

$$\frac{M}{L} = 0.6\ \text{gm cm}^{-1} = \frac{0.6 \times 10^{-3}}{10^{-2}}\ \text{kg m}^{-1} = 6 \times 10^{-2}\ \text{kg m}^{-1}$$

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$B = 0.1\ T, g = 10\ ms^{-2}$

$$\therefore \quad I = \frac{6 \times 10^{-2} \times 10}{10^{-1}}\ A = \mathbf{6A.}$$

Example 14. *A straight horizontal wire of length 0.5 m has a mass of 400 g. It is suspended horizontally by two massless threads attached to its two ends. A current of 50 A is set up in the wire. What is the magnitude and direction of externally applied magnetic field so that tension in each suspension thread is zero? If direction of current is reversed, what is tension in each thread?*

Solution :

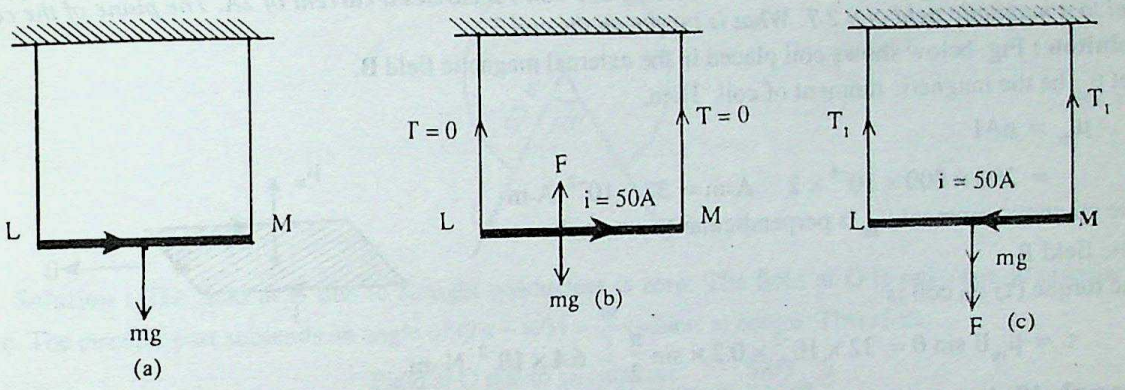

Fig. (a) shows wire LM suspended by threads. Fig. (b) shows forces acting on wire when it carries a current I = 50 A and tension in each thread is zero. Let F be force on wire due to applied perpendicular magnetic field. Since T = 0, F has a direction opposite to the weight of wire LM. According to Fleming's left hand rule, the direction of **B** is $\perp$ to wire LM and directed away from reader. Also

$$F = mg \text{ or } BIL = mg \quad B = \frac{mg}{IL} = \frac{0.4 \times 10}{50 \times 0.5}\ T = \mathbf{0.16\ T}$$

Fig. (c) shows forces acting when direction of current in wire in revesed. Let T_1 be tension in each wire. Then,

$$2T_1 = mg + F = mg + BIL = mg + mg$$

$$\therefore \quad T_1 = mg = 0.4 \times 10 = \mathbf{4N}.$$

Example 15. *What is the magnetic moment associated with a coil of 1 turn, area of cross-section $10^{-4}\ m^2$ carrying a current of 2A?* **(CBSE 1993)**

Solution : $\mu_m =$ The equivalent magnetic moment $= nAI$

Given $n = 1, A = 10^{-4}\ m^2, I = 2A.$

$\therefore \quad \mu_m = 1 \times 10^{-4} \times 2 \quad A\text{–}m = \mathbf{2 \times 10^{-4}\ A\text{–}m}.$

Example 16. *An electron at rest is accelerated by a p.d. of 500V. It enters a region having a perpendicular magnetic field of 0.2 T. What is radius of path of electron inside the magnetic field?*

Solution : Let v be speed acquired by electron when accelerated from rest by a potential of V volt. Then,

$$\frac{1}{2}\ mv^2 = eV \text{ or } v = \sqrt{\frac{2eV}{m}}$$

Let r be radius of circular path of electron inside perpendicular magnetic field B.

Then, $$\frac{mv^2}{r} = Bev \text{ or } r = \frac{mv}{Be}$$

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$$\therefore \quad r = \frac{m}{Be}\sqrt{\frac{2eV}{m}} = \frac{1}{B}\sqrt{\frac{2mV}{e}}$$

Given B = 0.2 T; V = 500 V, $e = 1.6 \times 10^{-19}$ C, $m = 9.1 \times 10^{-31}$ kg

$$\therefore \quad r = \frac{1}{0.2}\sqrt{\frac{2 \times 9.1 \times 10^{-31} \times 500}{1.6 \times 10^{-19}}}\ m = \frac{1}{0.2}\sqrt{56.87 \times 10^{-10}}\ m$$

$$= \frac{1}{0.2} \times 7.54 \times 10^{-5}\ m = 37.7 \times 10^{-5}\ m = \mathbf{0.377\ mm}$$

Example 17. *A coil of 200 turns has an area of 800 mm^2. It carries a current of 2A. The plane of the co parallel to a magnetic field of 0.2 T. What is torque on the coil.?*

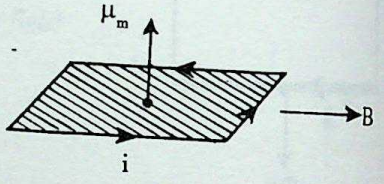
Soluiton : Fig. below shows coil placed in the external magnetic field **B**.

Let μ_m be the magnetic moment of coil. Then,

$$\mu_m = nAI$$

$$= 200 \times 800 \times 10^{-6} \times 2 \quad A\text{-}m = 32 \times 10^{-2}\ A\text{-}m$$

The magnetic moment μ_m is perpendicular to external magnetic field B.



The torque (τ) on coil is

$$\tau = \mu_m B \sin\theta = 32 \times 10^{-2} \times 0.2 \times \sin\frac{\pi}{2} = \mathbf{6.4 \times 10^{-2}\ N\text{–}m.}$$

Example 18. *A rectangular coil 6cm × 2cm having 200 turns is placed in a region of uniform magnetic fi of 0.1 T. What current be passed through it in order to keep it in equilibrium at an angle of 30° with the fie The restoring couple per unit twist of suspension wire is 10^{-6} N-cm degree^{-1}.*

Solution : The couple (c) acting on coil is = nABI

The restoring couple due to, twist in suspension will is $c\theta$, where c is torisonal rigidity of suspension wi In equilibrium

$$nABI = c\,\theta \Rightarrow I = \frac{c}{nAB}\theta$$

Given $c = 10^{-6}$ N–cm-degree^{-1}, n = 200; A = 12 $cm^2 = 12 \times 10^{-4}\ m^2$, B = 0.1 T; $\theta = 30°$

$$\therefore I = \frac{10^{-8} \times 30}{200 \times 12 \times 10^{-4} \times 0.1}\ A = 0.125 \times 10^{-4}\ A = 12.5 \times 10^{-6}\ A = \mathbf{12.5\ \mu A.}$$

Example 19. *A circular coil of 50 turns and radius 8cm carrying a current of 8A is suspended in a unifor horizontal magnetic field of 0.2 T. The megnetic lines of force make an angle of 60° with the normal to the co What external torque be applied to the coil to prevent it from turning? If the circular coil is replaced by a irregular shaped coil of same cross-sectional area, does the torque on coil change?*

Solution : To prevent coil from turning the externally applied couple must be equal and opposite to th couple on coil due to the magnetic field.

$\therefore$ Couple = nABI sin α,

where α is angle between the magnetic field and the normal to the plane of coil.

Given n = 50; $A = \pi r^2 = 3.14 \times (8 \times 10^{-2})^2 = 200.96 \times 10^{-4}\ m^2$, B = 0.2 T, I = 8A; $\alpha = 60°$

$\therefore$ Couple = $50 \times 200.96 \times 10^{-4} \times 0.2 \times 8 \times \sin 60° = \mathbf{1.39\ N\text{-}m.}$

The torque on planar coil does not depend on the shape of the coil. Since the area of coil remains same, th torque remains same.

Example 20. *In the Bohr model of the hydrogen atom the electron revolves round the nucleus in a circular orbit of radius 0.51 Å at frequency of 6.8×10^{15} r.p.s. What is magnetic field at the nucleus due to the electron?*

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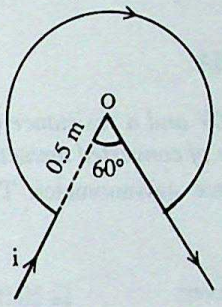
Solution : Electron moving in a circular orbit around nucleus is equivalent to a circular current carrying loop. The current (I) is $I = \frac{e}{T} = ev = 1.6 \times 10^{-19} \times 6.8 \times 10^{15}\ A = 10.88 \times 10^{-4}\ A$

$r = 0.51\ Å = 0.51 \times 10^{-10}\ m$

The magnetic field (B) at centre of circular orbit is

$$B = \frac{\mu_0 I}{2r} = \frac{4\pi \times 10^{-7} \times 10.88 \times 10^{-4}}{2 \times 0.51 \times 10^{-10}}\ T = \mathbf{13.4\ T.}$$

Example 21. *Fig. below shows a wire bent as shown carrying a current of 60 A. What is magnetic field at O?*



Solution : The field at O due to straight conductors is zero. The field at O is only due to circular part of wire. The circular part subtends an angle of $(2\pi - \pi/3) = \frac{5\pi}{3}$ radians at centre. Therefore,

$$\frac{\text{Field at O due to circular arc}}{\text{Field at O due to complete circle}} = \frac{5\pi/3}{2\pi} = \frac{5}{6}$$

$$\therefore \text{Field at O due to circular arc} = \frac{5}{6}\left[\frac{\mu_0 I}{2r}\right] = \frac{5}{6} \times \frac{4\pi \times 10^{-7} \times 60}{2 \times 0.5}\ T = \mathbf{2\pi \times 10^{-5}\ T.}$$

Example 22. *Find the force in kg–ωt per decameter length between two conductors 4 cm apart carrying currents of 2000 and 4000 A respectively. g = 10 ms^{-2}*

Solution : The force per unit length (F) between the two wires is $f = \frac{\mu_0 I_1 I_2}{2\pi a}$

Given $I_1 = 2000\ A,\ I_2 = 4000\ A;\ a = 4\ cm = 4 \times 10^{-2}\ m$

$$\therefore \quad f = \frac{4\pi \times 10^{-7} \times 2 \times 10^3 \times 4 \times 10^3}{2\pi \times 4 \times 10^{-2}}\ Nm^{-1}$$

The total force (F) on one decameter (= 10 m) of wire is

$$F = F \times 10 = 40 \times 10N = \frac{400}{10}\ \text{kg wt} = \mathbf{40\ kg\ wt.}$$

Example 23. *Electrons moving at right angles to a uniform magnetic field complete a circular orbit of radius 1 cm in 10^{-10}s. What is magnitude of the magnetic field?*

Solution : The radius (r) of circular orbit of electron in a perpendicular magnetic field is given by the relation.

$$\frac{mv^2}{r} = Bev \quad \text{or} \quad r = \frac{mv}{Be}$$

The time (T) taken to describe one circle

$$T = \frac{2\pi r}{v} = \frac{2\pi m}{Be} \quad \text{or} \quad B = \frac{2\pi m}{eT}$$

$$\therefore \quad B = \frac{2 \times 3.142 \times 9.1 \times 10^{-31}}{1.6 \times 10^{-19} \times 10^{-10}}\ T \approx \mathbf{0.57\ T.}$$

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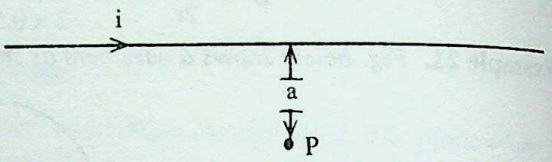
Example 24. *A long straight wire produces a magnetic field of* 8×10^{-6} *T. at a point distant 20 cm from the wire. What is current in wire?*

Solution :

The magnetic field B at a point P. due to an infinite, straight wire is

$$B = \frac{\mu_0 I}{2\pi a} \quad \text{or} \quad I = \frac{2\pi Ba}{\mu_0}$$

Given, $B = 8 \times 10^{-6}$ T; $a = 20$ c m $= 0.2$ m; $\mu_0 = 4\pi \times 10^{-7}$

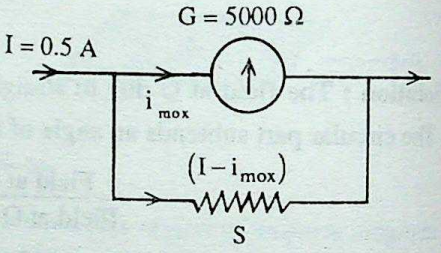


$$\therefore \quad I = \frac{2\pi \times 8 \times 10^{-6} \times 0.2}{4\pi \times 10^{-7}} \text{ A} = \mathbf{8A}.$$

Example 25. *A voltmeter has a range of 10V and a resistance of 5000Ω. How it can be converted into an ammeter reading up to 0.5 A? What is resistance of converted ammeter?*

Solution : A voltmeter is a high resistance galvanometer. The maximum current, I_{max}, voltmeter can withstand is $I_{max} = \frac{10}{5000} = 0.2 \times 10^{-2}$ A

Let S be the shunt resistance required to convert voltmeter into ammeter. From fig. alongside.



$$S = \frac{I_{max} \cdot G}{I - I_{max}} = \frac{0.002 \times 5000}{(0.5 - 0.002)}$$

$$= \frac{2 \times 10^{-3} \times 5 \times 10^{3}}{498 \times 10^{-3}} \approx 20.08 \ \Omega$$

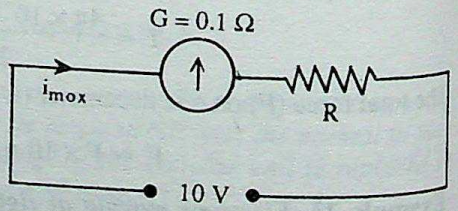
Since S and G are in parallel, the resistance of converted ammeter (R_{AM}) is

$$R_{AM} = \frac{GS}{G+S} = \frac{5000 \times 20.08}{5020.08} \ \Omega \approx \mathbf{20.0\ \Omega}.$$

Example 26. *An ammeter has a resistance of 0.1 Ω and range of (0 – 0.01 A). How it can be converted into a voltmeter reading up 10 volt?*

Solution : An ammeter is a low resistance galvanometer. Given $G = 0.1\ \Omega$; $I_{max} = 0.01$ A

Let R be series resistance required to convert it into a voltmeter reading up 10 volt as shown in fig. below. From fig.,



$$I_{max} = 0.01 = \frac{10}{R + 0.1}$$

$$\therefore \quad R + 0.1 = \frac{10}{0.01} = 1000$$

or $\mathbf{R = 999.9\ \Omega}$.

Example 27. *Calculate the current and voltage senstivity of a moving coil galvanometer having 100 turns of coil each of cross-sectional area 15 cm*^{2}*. The resistance of galvanometer is 40 Ω.*

The magnetic field of horse shoe magnet is 0.2 T. The torsional rigidity of suspension wire is 10^{-8} *N-m degree*$^{-1}$.

Solution : By definition; I_s = current senstivity $= \frac{nAB}{c}$

Given, $n = 100$; $A = 15\ cm^2 = 15 \times 10^{-4}\ m^2$, $B = 0.2$ T, $c = 10^{-8}$ N-m degree^{-1}

$$\therefore \quad I_s = \frac{10^2 \times 15 \times 10^{-4} \times 0.2}{10^{-8}} (\text{A/degree})^{-1} = \mathbf{3 \times 10^6\ degree\ A^{-1}}$$

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Also, the voltage sensitivity V_s

$$V_s = \frac{I_s}{R} = \frac{3\times10^6}{40} = 7.5\times10^4 \text{ degree/volt.}$$

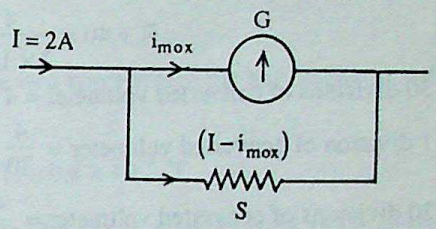
Example 28. *A galvanometer of resistance 30 Ω has a current capacity of 2 mA. How it can be converted into an ammeter reading upto 2A? What is resistance of converted ammeter?*

Solution : For given galvanometer,

$$G = 30\ \Omega,\ I_{max} = 2\text{mA} = 0.002\text{A}$$

Let S be shunt resistance required to convert it into an ammeter of range (0–A)

From fig. alongside



$$\frac{I_{max}}{I - I_{max}} = \frac{S}{G} \text{ or } S = \frac{G\,I_{max}}{I - I_{max}}$$

$$\therefore \quad S = \frac{30\times2\times10^{-3}}{(2-0.002)}$$

$$= \frac{30\times2\times10^{-3}}{1.998}\ \Omega \approx 0.03\ \Omega$$

Since G and S are connected in parallel, the resistance of converted ammeter (R_{Am}) is

$$\frac{1}{R_{Am}} = \frac{1}{G} + \frac{1}{S} = \frac{1}{30} + \frac{1}{0.03}$$

$$\therefore \quad R_{Am} = \frac{30\times0.03}{30.03}\ \Omega \approx \mathbf{0.0299\ \Omega.}$$

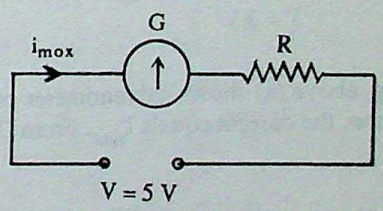
Example 29. *A galvanometer has a current sensitivity of 0.1mA per division. There are 50 divisions on galvanometer scale and its resistance is 100 Ω. How it can be converted into a voltmeter reading up to 5V? What is resistance of converted voltmeter?*

Solution : Given I_s = current sensitivity of galvanometer = 0.1 mA/div.

θ = total number of divisions on galvanometer scale = 50

$$\therefore I_{max} = i_s \times \theta = 0.1\times50 \text{ mA} = 5\text{ mA} = 5\times10^{-3}\text{ A}$$

Let R be series resistance required to convert galvanometer into voltmeter as shown in fig. alongside.



Obviously, $I_{max} = \frac{5}{R+G}$ or $5\times10^{-3} = \frac{5}{R+G}$

$$\therefore \quad R + 100 = \frac{5}{5\times10^{-3}} = 1000$$

or $$R = 900\ \Omega$$

Since R is joined in series with the galvanometer, the resistance (R_{volt}) of converted voltmeter is

$$R_{volt} = R + G = \mathbf{1000\ \Omega.}$$

Example 30. *An electron is projected with a speed of 10^5 ms^{-1} of right angles to a magnetic field of 0.019 G. Calculate the radius of the circle described by the electron.* **(CBSE 1990)**

Solution : The radius (r) of the circular path described by a charged particle in a perpendicular magnetic (B) is given by $\frac{mv^2}{r} = Bqv$ or $r = \frac{mv}{Bq}$

Given $v = 10^5\ ms^{-1}$; $q = 1.6\times10^{-19}$ C; $B = 0.019\ G = 0.019\times10^{-4}$T, $m = 9.1\times10^{-31}$ kg

$$\therefore \quad r = \frac{9.1\times10^{-31}\times10^5}{1.9\times10^{-6}\times1.6\times10^{-19}}\ \text{m} \approx \mathbf{0.3\ m.}$$

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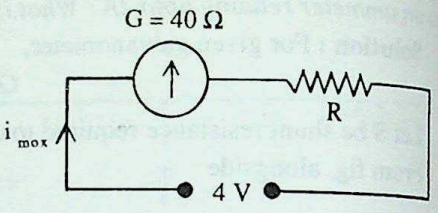
Example 31. *A galvanometer of resistance 40Ω has $I_{max} = 2mA$. How it can be converted into a voltmeter reading up to 4V. What is the applied p.d. if the converted galvanometer gives a deflection of 20 div.? The total number of divisions on galvanometer scale is 30.*

Solution : Let R be series resistance required to convert galvanometer into voltmeter as shown in fig below:

Then,



$$I_{max} = \frac{4}{R+40}$$

or $$2\times10^{-3} = \frac{4}{R+40}$$

$$\therefore \quad R+40 = \frac{4}{2\times10^{-3}} = 2000 \text{ or } R = 1960\ \Omega$$

30 divisions of converted voltmeter = 4V

1 division of converted voltmeter = $\frac{4}{30}$ V

$\therefore$ 20 divisions of converted voltmeter = $\frac{4}{30}\times 20$ V = **2.67 V**

Example 32. *A galvanometer of resistance 40Ω shows a full scale deflection when connected to a battery of p.d. 3V through a series resistance of 260 Ω. How it can be converted into.*

(i) an ammeter reading up to 1A?

(ii) a voltmeter reading up to 25 V?

Solution :

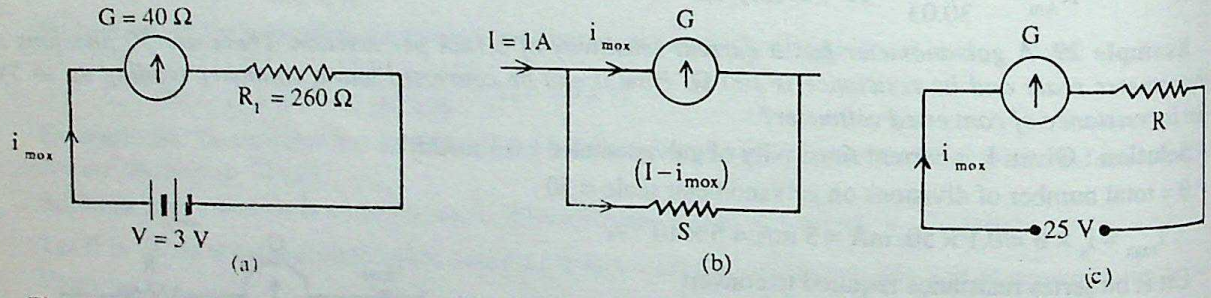


Fig. above (a) shows galvanometer connected to battery of p.d. 3V. Since the galvanometer shows full scale deflection, the current equals I_{max}. From Ohm's law

$$I_{max} = \frac{3}{(260+40)} = 0.01\ A$$

(i) Fig. above (b) shows the shunt resistance S so that galvanometer is converted into ammeter.

Obviously, $\frac{I_{max}}{I-I_{max}} = \frac{S}{G} \Rightarrow S = \frac{I_{max}\,G}{I-I_{max}} = S = \frac{0.01\times40}{1-0.01} = \frac{0.01\times40}{0.99}\ \Omega \approx \mathbf{0.4\ \Omega}$.

(ii) Fig. above (c) I_{max} shows series resistance (R) connected to galvanometer so that it becomes a voltmeter. Clearly,

$$I_{max} = \frac{25}{R+G} \text{ or } 0.01 = \frac{25}{R+40}$$

$\therefore$ $R+40 = \frac{25}{0.01} = 2500 \Rightarrow R = 2500-40 = 2460$ $\therefore$ **R = 2460 Ω.**

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Example 33. *Two long straight wires are placed 10 cm apart. The two wires carry same current of 2A in same direction. What is net magnetic field at a point mid way between the two wires?*

Solution :

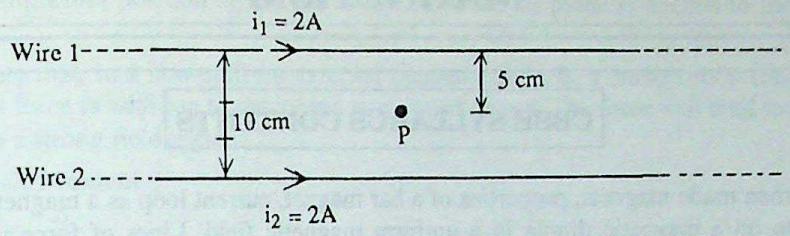

fig above shows the arrangement. P is point mid-way between the two wires where the net magnetic field is to be calculated.

B_1 = magnetic field at point P due to wire 1 = $\dfrac{4\pi \times 10^{-7} \times 2}{2\pi \times 5 \times 10^{-2}}$ T $= 0.8 \times 10^{-5}$ T

The direction of $\mathbf{B}_1$ according to right-hand screw rule, is perpendicular to plane of page and directed away from reader.

B_2 = magnetic field at point P due to wire 2 = $\dfrac{4\pi \times 10^{-7} \times 2}{2\pi \times 5 \times 10^{-2}}$ T $= 0.8 \times 10^{-5}$ T

The direction of $\mathbf{B}_2$ according to right-hand screw rule is, i.e., perpendicular to plane of page and direction towards reader. Since $\mathbf{B}_1$ and $\mathbf{B}_2$ are equal in magnitude and opposite in direction the *resultant field at* P *is* ***zero.***

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Unit – V

MAGNETISM

CBSE SYLLABUS CONTENTS

Natural and man made magnets, properties of a bar magnet, current loop as a magnetic dipole, magnetic moment as torque on a magnetic dipole in a uniform magnetic field. Lines of force in a magnetic field. Comparison of bar magnet and solenoid. Earth's magnetic field and its source (elementary idea). Tangent galvanometer, vibration magnetometer. Para, dia and ferro-magnetic substances with examples. Electromagnets and permanent magnets.

No. of periods allotted : 10 out of 168

No. of marks allotted : 4 out of 70.

BASIC FACTS AND FORMULAE

Natural Magnets

A lump or strip of magnetite, which has the property of attracting small pieces of iron, and which points along the north-south direction when freely suspended, constitutes a natural magnet.

The Bar Magnet

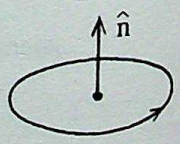
The natural magnets have irregular shape and they are weak. When a piece of iron or steel is rubbed with a magnet, it acquires magnetic properties. Such magnets are called artificial magnets. Artificial magnets have desired shape and strength. A bar magnet, a magnetic needle, a horse shole magnet, etc., are examples of artificial magnet. The regions of greatest attraction in a magnet are called the poles and the straight line joining them is the magnetic axis. The magnetic equator or neutral line is the region mid-way between the poles where there is no attraction.

The end of a freely suspended bar magnet which always points towards the north is called the north pole (N) and the other end the south pole (S).

Like poles repel and unlike poles attract one another. The two poles are always of equal strength.

A Current Loop as Magnetic Dipole

A small current carrying loop shows properties similar to bar magnet or a magnetic dipole. We associate an equivalent magnetic moment, μ_m, with current loop as follows :



(i) The *magnitude* of the magnetic moment associated with a current carrying loop equals the product of the current in it and its area. Thus,

$$|\mu_m| = \mu_m = IA$$

(ii) The *direction* of the magnetic moment vector is normal to the plane of the loop and is in the sense of advance of a right handed screw rotated around the loop in the sense in which the current is flowing through it. Thus,

$$\mu_m = IA\hat{n}$$

Torque on a Current Loop in a Magnetic Field

A magnet, of magnetic moment μ_m, experiences a torque τ, in a uniform external magnetic field **B**, where

$$\tau = \mu_m \times B$$

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It follows that, a current loop, when kept in a uniform magnetic field **B**, will experience a torque τ

where $\tau = (IA\hat{n} \times \mathbf{B})$

The torque will thus, try to orient the coil so that $\hat{n}$ is parallel to **B.** Now $\hat{n}$ is *normal* to the plane of the coil. It follows that the equilibrium position of the coil is one in which its plane is normal to the external magnetic field.

We must also note that, in a non-uniform external magnetic field **B,** a current loop (or a magnetic dipole) will also experience a force in addition to the torque mentioned above. The force will tend to move the coil from a weak field region to a strong field region.

Definition of Magnetic Moment

We have $\tau = \mu_m \times \mathbf{B}$

Hence, $|\tau| = \tau = \mu_m B \sin\theta$

$\therefore$ If B = 1 unit and $\theta = \pi/2$, $\tau = \mu_m$. We may thus, say,

The magnetic moment of a magnet equals the magnitude of the torque experienced by it when it is kept at right angles to a uniform magnetic field of 1 tesla.

It follows that the units of the magnetic moment are N-m/T *or newton-meter per tesla.*

Lines of Force in a Magnetic field

A line of force is a line (or curve) along which an isolated north pole would travel if free to move in a magnetic field. It is such that the tangent to it at any point gives the direction of the resultant force at the point. The lines of force grouped together form the tubes of induction. If we choose such a scale that a unit pole sends out one tube of force per square centimeter, the tube is called a unit tube. The strength of the field is inversely proportional to the cross-section of the unit tube and directly proportional to the number of unit tubes per square centimetre taken perpendicular to their direction.

Lines of Force Patterns for some Standard cases

We show below the lines of force of the combined magnetic field of a bar magnet and the earth for four different orientations of the bar magnet. The *neutral points* (the point where the fields of the bar magnet and the earth cancel each other, so that the resultant field there is zero) are also shown is each case.

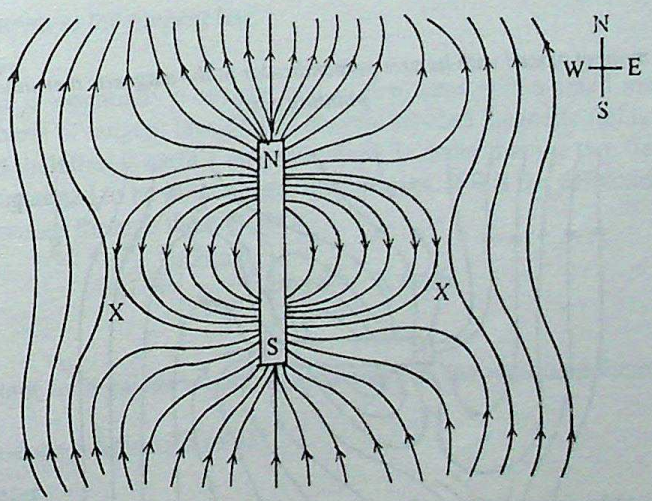

Fig. (a) : Field due to a bar magnet placed with its axis along the magnetic meridian of the earth and its north pole pointing north.

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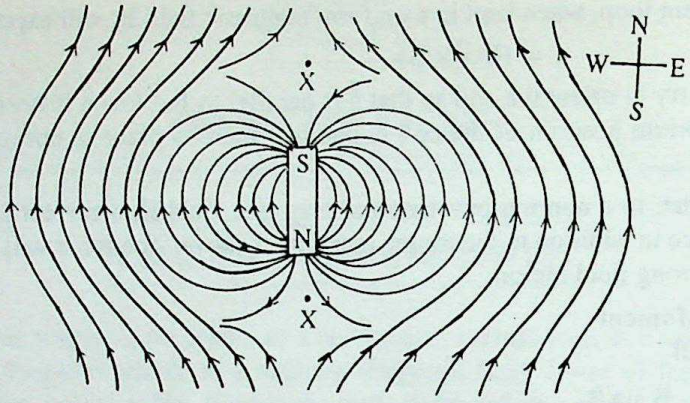

Fig. (b) Field due to a bar magnet placed with its axis along the magnetic meridian of the earth and its north pole pointing south.

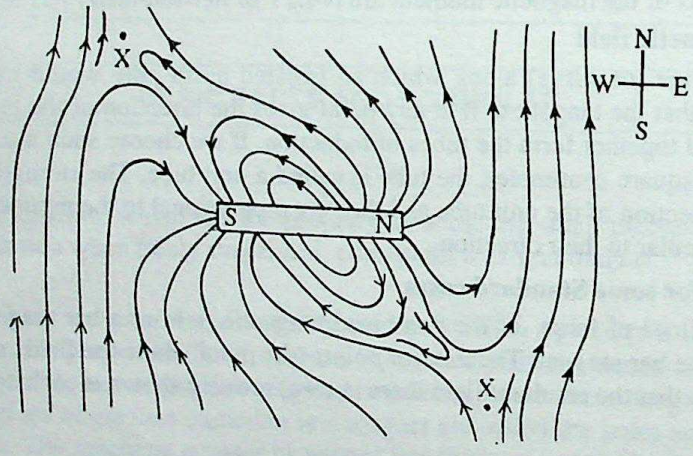

Fig. (c) Field due to a bar magnet placed with its axis perpendicular to the magnetic meridian of the earth and its north pole pointing east.

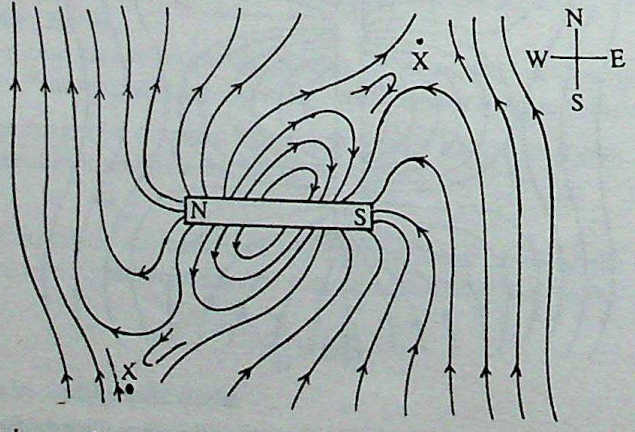

Fig. (d) : Field due to a bar magnet placed with its axis perpendicular to the meridian of the earth and its north pole pointing west.

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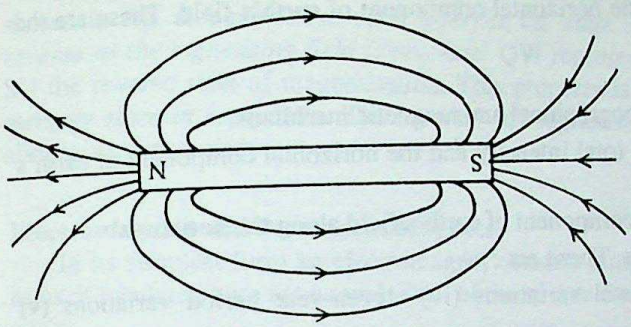
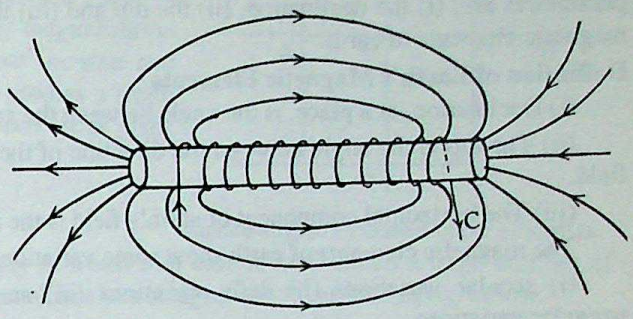
The Bar Magnet and the Solenoid

The magnetic field of a current carrying solenoid is very similar to that of a bar magnet. The *lines of force* patterns for the two cases are as shown.



Magnetic field of a bar magnet.



Magnetic field due to a straight solenoid.

We may note that :

The two ends of the solenoid are analogous to the poles of a bar magnet. For all practical purposes we can consider the magnetic field of a bar magnet and a straight solenoid as identical. It should, however, be noted that in a solenoid,

(i) the strength of magnetic field can be increased or decreased by increasing or decreasing the current, and

(ii) the direction of the magnetic field depends on the direction of the current. If current is reversed the magnetic field is also reversed.

The Tangent Law

If a magnet is suspended freely in the region of *two uniform fields at right angles* to one another, it comes to rest with its axis pointing in the direction of the resultant field. Mathematically,

$$B_2 = B_1 \tan\theta,$$

where B_1 and B_2 are two uniform fields at right angles to one another and θ is the angle that the magnet makes with direction B_1. This is known as the *tangent law.*

The Tangent Galvanometer

A tangent galvanometer is essentially a circular coil of few turns with a small magnetic needle pivoted at the centre. It works on the basis of tangent law. Out of the two crossed magnetic fields one is due to the current passing through the coil and the other is earth's magnetic field. In order that the two fields be at right angles the plane of the circular coil is arranged to be in the magnetic meridian. If θ is the deflection of the magnetic needle when a current of I ampere passes through the coil, then

$$I = \left(\frac{2\pi a B_E}{\mu_0 n}\right) \tan\theta = K \tan\theta,$$

where $K = \dfrac{2\pi a B_E}{\mu_0 n}$ is a constant for a galvanometer and is known as the *reduction factor.* It is numerically equal to the current required to produce a deflection of 45°.

The Vibration Magnetometer

If a magnet is suspended by a torsionless string in a uniform field such that it is free to vibrate in a horizontal plane about a vertical axis, and then displaced from its equilibrium position, the magnet will vibrate in the field with time-period T given by the relation

$$T = 2\pi \sqrt{\frac{I \mu_0}{MB}}$$

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where I is the moment of inertia of the magnet about the axis of rotation, M is the magnetic moment of the magnet and B is the magnetic flux density.

Earth's Magnetic Field

The earth's field, at any place, is a vector quantity; hence, it requires three parameters. These three parameters are: (i) the declination, (ii) the dip and (iii) the horizontal component of earth's field. These are the magnetic elements of earth.

Definition of Earth's Magnetic Elements

(i) Declination, at a place, is the angle between the geographical and magnetic meridians.

(ii) The dip is the angle between the direction of the total intensity and the horizontal component of earth's field.

(iii) The horizontal component of earth's field is the component of earth's field along the horizontal.

The magnetic elements of earth show some variations. These are :

(i) secular variations (ii) daily variations (iii) annual variations (iv) eleven-year period variations (v) irregular variations.

Different Types of Magnetic Materials

On the basis of their response to an external magnetising field, materials are divided into *three* categories:

(i) *Diamagnetic* materials move *away* from the region of a *strong magnetic field.*

(ii) *Paramagnetic* materials move *towards* the region of the stronger magnetic field.

(iii)Ferromagnetic materials can be thought of as *very strong paramagnetics.* However, they also show some special properties of their own.

Properties of Diamagnetics

The main properties of diamagnetic materials are: (i) They move away from the region of stronger magnetic field. (ii) Align themselves in a direction perpendicular to that of the magnetic field. (iii) Susceptibility χ is small and negative. (iv) χ is independent of temperature. (v) The relative permeability, μ_r, is less than unity. (vi) Magnetisation is in a direction opposite to that of the applied field. (vii) It is a universal property.

Properties of Paramagnetics

The main properties of paramagnetic materials are : (i) They move towards the region of the stronger magnetic field. (ii) Align themselves parallel to the field direction. (iii) Magnetic susceptibility χ is a small positive number.(iv) Susceptibility χ depends on temperature. According to Curie's law : $\chi = C/T$, where C is constant known as Curie's constant. (v) The intensity of magnetisation **I** depends on the magnetising field **H.** I = **C (H/T).** The maximum value of intensity of magnetisation is the saturation value. (vi) The relative permeability μ_r is greater than unity. (vii) Magnetisation is in the direction of magnetising field.

Properties of Ferromagnetics

The main properties of ferromagnetic materials are : (i) They are very strongy paramagnetic materials. (ii) The magnetisation is not a single valued function of the magnetising field. (iii) There exists a critical temperature, T_c, known as *Curie temperature.* If temperature T of material is below Curie temperature (*i.e.*, $T < T_c$) it behaves as ferromagnetic. But for $T > T_c$, the behaviour of the material is paramagnetic. (iv) Susceptibility χ depends on temperature and varies according to relation $\chi = C/T - T_c$. This is *Curie-Weiss law.* (v) Relative permeability μ_r is a large, positive number. (vi) The magnetisation produced depends not only on the value of magnetising field but also on the past magnetic and mechanical history of the material. (vii) Ferromagnetics exhibits hysteresis, *i.e.*, magnetisation lags behind magnetising field. The amount of magnetisation present, when magnetising field is reduced from **H** to zero, is a measure of reduced magnetism. The field, in the reverse direction, required to make magnetisation zero is called the *coercivity.* The area of hysteresis loop is a measure of the energy lost in one cycle of magnetisation.

Hysteresis Curve

The nature, and area of hysteresis curve is an important deciding factor in the design of (i) permanent magnets (ii) electromagnets (iii) core of transformer or choke.

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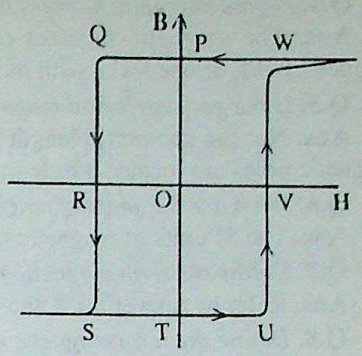
Ferrites

Ferrites are composite oxides of iron having properties similar to ferromagnetics. Ferrites are semi-conductors. They are finding an increasing use at radio frequencies and in computer engineering.

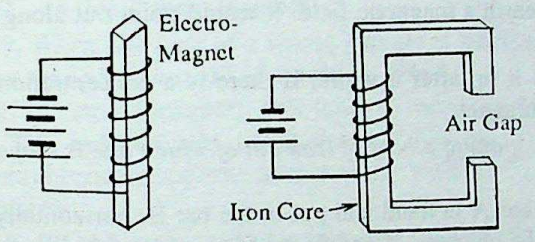
A special class of ferrites have a *square-shaped hysteresis curve* as shown in fig. alongside. For such a *ferrite* the *state of magnetisation reverse as the mgnetising field is reversed.* QW represents one state and SU the reverse state of magnetisation. This property is used as a small *memory store in computers.* The reversal of magnetisation takes place almost instantaneously.

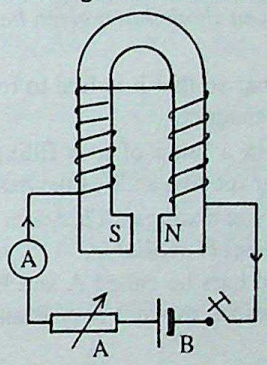


Square-shaped hysteresis curve of ferrites.

Electromagnets and Permanent Magnets

In its simplest form an electromagnet consists simply of a soft iron core around which a large number of turns of insulated wire are wound. Two of the simple form of an electromagnet are illustrated in fig. below.





We also often make use of a U *shaped* or a *horse shoe type* electromagnet. For this, fine insulated wire is wound around the two arms of the 'U' *in opposite* sense. Because of this opposite sense 'windings', the current in the two arms appears (when viewed from the bottom) clockwise in one arm and anticlockwise in the other. The two ends of the two 'arms', thus, acquire opposite polarities and a U-shaped (or horse shoe shaped) electromagnet results.

The *solenoid* can also be regarded as an *electromagnet.* It is usually a strong electromagnet only if it has a soft iron core placed inside it.

Whereas an electromagnet is only a temporary magnet, we often need permanent magnets. These are made from suitable ferromagnetic alloys which have the characteristic already discussed. As noted there, permanent magnets are usually made from *cobalt steel, alnico* or *tincal.* Their two common shapes are : (i) bar magnets and (ii) horse shoe magnets.

SUBJECTIVE QUESTIONS ON UNIT – V

Q.1. *What is a magnet?* **(1)**

Ans. A magnet (usually a bar of magnetised iron) is characterized by the following two properties :

(i) It attracts small pieces of iron (iron fillings) towards it.

(ii) It points along the north-south direction, when freely suspended, in the earth's magnetic field.

Q.2. *What are natural magnets?* **(1)**

Ans. A lump or strip of *magnetite,* having the above two properties, is a *natural magnet.*

Q.3. *Why are artificial magnets preferred to natural magnets?* **(1)**

Ans. Artificial (or man-made) magnets are preferred to natural magnets because

(i) Their strength is usually much stronger.

(ii) They can be moulded into desired shapes and size.

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Q.4. *Define magnetic moment of a magnet.*

Ans. The magnetic moment of a magnet equals the torque experienced by it when kept in a unifo magnetic field, of one tesla, with its axis *normal* to the direction of this field.

Q.5. *Is the geometric and magnetic length of a magnet same?*

Ans. No; the geometric length is a little more than the magnetic length of the magnet. [This is because magnetic poles are located a little inside the edges of the magnet.]

Q.6. *What are S.I. units of magnetic moment?*

Ans. The SI units of magnetic moment are N-m/tesla **or** ampere-metre^2 **or** joule/tesla.

Q.7. *Define the term magnetic moment.* **(CBSE 1995)**

Ans. Refer to answer no. 4 above.

Q.8. *Define the term magnetic moment. Give its S.I. unit.* **(CBSE 1993 Comptt.)**

Ans. Refer to answer no. 4 and 6 above.

Q.9. *Do separate north and south pole exist?*

Ans. No: we, so far, have no evidence about the separate existence of the north and south poles.

Q.10. *How can you show that a given bar is a magnet, without the help of any other equipment?*

Ans. We may

(i) suspend the bar so that it is free to rotate in the earth's magnetic field. It would point out along the N direction only if it is magnet.

(ii) put the bar in a lump of iron fillings and pick it up after a while. If there is a concentration of iro fillings, sticking, near the two ends of the bar, the bar is magnet.

Q.11. *How will you distinguish between two similar looking pieces of iron out of which one is magnet wh no additional equipment is available?*

Ans. Let the two bars be called A and B. Hold the bar A in hand and put in the bar B, horizontally, on th table. Keeping A vertical, move it over B and observe the changes, if any in the force of attraction between th two bars.

If the force remains constant throughout, bar A (*i.e.,* the bar in hand) is the magnet.

If the force is strong at the two ends of bar B, and becomes almost negligible at its centre, bar B is th magnet.

[Note : A magnet's magnetic attraction is strongest at its two ends - its poles - and almost zero at its centre

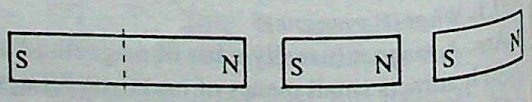
Q.12. *A magnet attracts only a magnet. How will you justify this statement?*

Ans. We know that a magnet can attract

(i) another magnet (if their unlike poles are facing each other) and (ii) an unmagnetised piece of iro However, if we look at the second case a little more closely, we notice that when the magnet's N-Pole, say, brought near an unmagnetised bar it *induces* a S-pole at its near end and a N-pole at its far end. Because th induced S-pole is nearer, the attraction of the magnet's N-pole on it is greater than its repulsion on the induce (farther off) N-pole. The net result is an attraction of the 'unmagnetised' bar. However, the attraction has real come about again as an interaction between a N-pole and a S-pole. We may, therefore, say that inductio precedes attraction and the observed attraction is *always* due to an interaction between a N-pole and a S-pole.

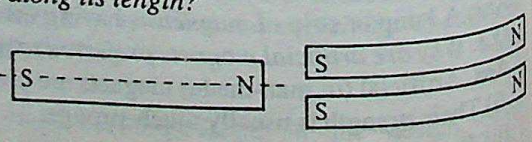
Q.13. *What happens if a bar magnet is cut into two pieces transverse its to the length?*

Ans. When a bar magnet is cut into two pieces transverse to its length, each half again become a complete magnet. The magnetic moment of each of these 'half magnets', are however, half of the magnetic moment of the original magnet.



Q.14. *What happens if a bar magnet is cut into two pieces along its length?*

Ans. When a bar magnet is cut into two pieces along its length, each half is again a complete magnet. The magnetic moment of each half is again half of that of the original magnet.



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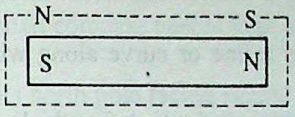
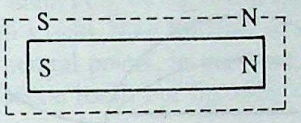
Q.15. *What is the effect of placing two equal magnets, end to end with opposite poles in contact?* (1)

Ans. When the two magnets are so placed, the combination effectively acts as an unmagnetised bar.



Q.16. *What is the effect of placing two equal magnets end to end with their like poles in contact?* (1)

Ans. When the two magnets are placed end to end, with their like poles in contact, the combination acts like a stronger magnet with a magnetic moment (almost) double of that of each of the magnets.



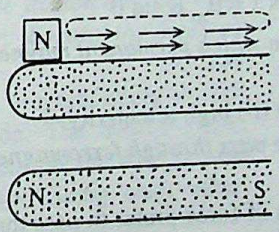
(**Note :** To counteract the forces of repulsion, such a combination can be kept '*intact*' only by using some thread, etc., to 'bind' them together)

Q.17. *When one pole of a strong magnet is suddenly brought near a similar pole of another weak magnet, attraction take place instead of repulsion. Why?* (2)

Ans. The strong magnets, pole tends to induce a polarity opposite to its own on the nearer end of the weaker magnet. This induced pole, being stronger than the original 'pole' of the weak magnet, the net 'pole' (at this nearer end) becomes opposite to that of the 'pole' of the strong magnet. Hence, we observe an attraction instead of a repulsion.

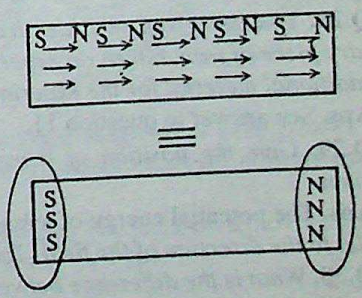
Q.18. *What happens when a test tube loosely filled with iron fillings is laid horizontally on a table and stroked with one pole of a magnet several times in the same direction?* (2)

Ans. The test tube starts behaving like a magnet. If, say, the tube is being stroked with the N-pole, moving from left to right, the right end of the tube will become a S-pole and its left end would become a N-pole.



Q.19. *Why is magnetism concentrated at the ends of a magnet?* (2)

Ans. We can understand this in terms of the molecular theory of magnetism. According to this theory, each molecule is equivalent to a magnetic dipole. In a magnetized bar (*i.e.*, a magnet), these molecular dipoles get aligned or arranged in a systematic way as shown. We observe that apart from the ends, the presence of the opposite poles (touching each other) tends to cancel the magnetism of the bar. We, therefore, observe a 'concentration' of the magnetism of the bar only at its two ends.



Q.20. *What happens if an iron bar magnet is melted? Does it retain its magnetism?* (2)

Ans. No, an iron bar magnet does not retain its magnetism on melting. A bar gets magnetised only when its molecular dipoles get arranged in an orderly way. On melting, the molecular dipoles arrangement (present in the magnetised bar) gets 'converted' into a *completely random and chaotic one.* (The high temperature attained during melting helps this randomization). There is, therefore, no net magnetism in the molten sample.

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Q.21. *How is a gauss related to a tesla?*

Ans. We have one gauss = 10^{-4} tesla or 1 tesla = 10^4 gauss

Q.22. *What are magnetic lines of force?*

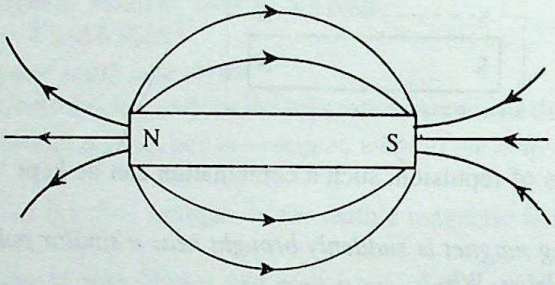
Ans. A magnetic line of force was defined as a line or curve along which an isolated north pole would travel, if free to move in the given magnetic field.

Since an isolated north pole does not exist, we now prefer to define the lines of force as follows :

A magnetic line of force is that curve for which the tangent to the curve, at every point, gives the direction of the magnetic field at that point.

Q.23. *Roughly trace the magnetic field lines for a bar magnet.*

Ans. The pattern of the lines of force of a bar magnet is roughly of the form shown



Q.24. *Draw a diagram showing the lines of magnetic field around a bar magnet, placed along the magnetic meridian, with its north pole pointing towards the geographical north.* **(CBSE 1994 Comptt.)**

Ans. Refer to the lines of force diagrams (of a bar magnet) shown under 'Basic facts and formulae of unit 5.

Q.25. *Give the expression for the couple acting on a magnet of magnetic moment M suspended in a uniform magnetic induction field* **B** *at a angle* θ *with the field.*

Ans. The couple acting on a magnet, of magnetic moment μ_m, when it is present in a uniform magnetic field **B**, is given by $\tau = \mu_m \times \mathbf{B}$

Hence, the required magnitude of the couple is $\tau = \mu_m B \sin\theta$

Q.26. *Mention two properties of the alloy from which permanent magnets are made.*

(CBSE 1997 Comptt.)

Ans. The alloy should have (i) high coercivity (ii) high retentivity.

Q.27. *Why do magnetic lines of force prefer to pass through ferromagnetic substances than through air?*

(CBSE 1997 Comptt.)

Ans. Due to high permeability, magnetic lines of force prefer to pass through ferromagnetic substances than through air.

Q.28. *You are given two identically looking bars A and B. One of these is a bar magnet and other an ordinary piece of iron. Given an experiment to identify which one of the two is a bar magnet. You are not to use any additional material for the experiment.*

Ans. See answer to question 11. **(CBSE 1998)**

Q.29. *Give the position of a magnetic dipole, held in a magnetic field, where its potential energy is minimum.*

Ans. The potential energy of a magnetic dipole, held in a magnetic field, is minimum when *its dipole axis is parallel to the direction of the field.* This is, therefore, the position of stable equilibrium of the magnetic dipole. **(CBSE 1993)**

Q.30. *What is the difference between a neutral point and a null point?*

Ans. A *neutral point* is defined in the context of the lines of force of a bar magnet kept in the earth's magnetic field. At this point, the field of the bar magnet cancels that of the earth and the net magnetic field is zero.

A *null point,* however, is used in a general sense, and is any point where the net magnetic field is zero. From a physical point of view, the two are thus, equivalent.

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Q.31. *Define neutral point. Locate the position of neutral points when a small bar magnet is placed with its north pole (i) towards north of the earth (ii) towards south of the earth.* **(CBSE 1995 Comptt.) (3)**

Ans. The neutral point is that point where the field of a given magnet cancels that of the earth, so that the net magnetic field there is zero. A small compass needle kept at this point could, therefore, point in any arbitrary direction.

Let a bar magnet be kept with its north pole facing north. Its magnetic moment vector is then pointing *from south to north.* This is also the direction of the earth's magnetic field. At the neutral point, the bar magnet's field must point from N to S to cancel the field of the earth. This, we know, would be the situation, in this case, on the equatorial line of the magnet. [At the equatorial line, the field of a magnet is anti parallel to its magnetic moment vector]. The neutral points, in this case, would, therefore, be on the equatorial line of the magnet, *i.e.,* along the east west direction. For fig. refer to lines of force diagrams, shown under Basic facts and formulae.

When the magnet is kept with its south pole facing north, its magnetic moment vector is from S to N, *i.e.,* anti parallel to the direction of the earth's field. Now the field of a magnet is along the direction of its magnetic moment vector on its *axial line.* The neutral points, in this case, would, therefore, be on the axial line of the magnet, *i.e.,* along the north south direction itself. For fig. refer to lines of force diagrams, shown under Basic facts and formulae.

Q.32. *While tracing the magnetic field, why is the compass needle suddenly reversed in direction as it crosses the neutral point?* **(2)**

Ans. At the neutral point, the magnetic field of the magnet is just equal and opposite to that of the earth. Just before the neutral point, the field of the magnet is stronger, and just after it, this field is weaker than that of the earth. The compass needle would, therefore, show a sudden reversal in direction as it crosses the neutral point.

Q.33. *Why cannot two magnetic lines of force intersect?* **(2)**

Ans. If two magnetic lines of force were to intersect, the field at the point of intersection could be along any of the two directions, corresponding to the tangents to the two lines at this point. This is physically not permissible. Hence, two lines of force cannot intersect.

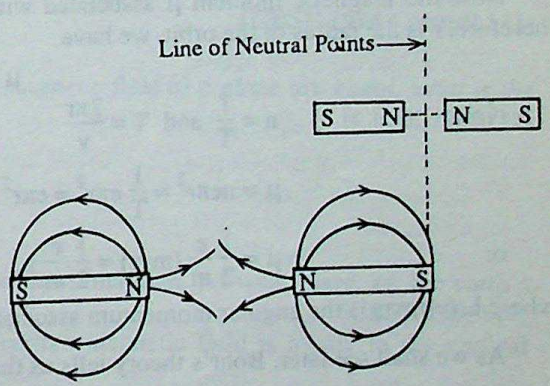
Q.34. *Can two magnetic lines of force intersect? Justify your answer.* **(CBSE 1993) (2)**

Ans. Refer to answer no. 33 above.

Q.35. *Draw the magnetic lines of force when two identical magnets are placed a finite distance apart with identical poles facing one another. Locate the neutral points.* **(3)**

Ans. The lines of force pattern, corresponding to this case, are as shown in fig. alongside. The neutral point would be the collection of all points on the line drawn normal to the line, joining the two 'facing each other poles', and bisecting it.

(The neutral points have been shown here in the context of the fields of the two magnets, neglecting the field of the earth).



Q.36. *Magnetic field lines show the direction at every point which a small magnetised needle takes up at that point. Do the magnetic field lines also represent the lines of force on a moving charged particle at every point?* **(1)**

Ans. No; the magnetic lines of force give the direction of the magnetic field. The force on a moving charged particle is, however, at right angles to the direction of the magnetic field. ($\mathbf{F} = q\ (\mathbf{v} \times \mathbf{B})$.

Q.37. *Does a bar magnet exert a torque on itself due to its own field?* **(1)**

Ans. No, there is no torque on a bar magnet due to its own field.

Q.38. *What are the two simplest sources of magnetic field?*

Ans. The simplest sources of a magnetic field are :

(i) a moving charged particle

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(ii) a magnetic dipole or a magnet.

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Q.39. *Magnetic field arises due to charges in motion. Can a system have magnetic moment even though its net charge is zero?*

Ans. Yes; a system can have a magnetic moment even though its *net* charge is zero. (The *neutron*, a neutral particle, for example has a non-zero magnetic moment associated with it).

Q.40. *Why is there a similarity in the magnetic field due to a straight solenoid and the magnetic field of a bar magnet.*

Ans. Every single turn, of a current carrying solenoid, has a magnetic moment associated with it. The whole solenoid, therefore, has a net magnetic moment N times that of a single turn. We can thus, think of a solenoid as equivalent to a bar magnet of this net magnetic moment. The field of a solenoid would, therefore, be similar to that of a bar magent.

Q.41. *What is the magnetic moment associated with a current loop?*

Ans. The magnetic moment, associated with a current loop is the current times the area of the loop. The direction is given by the right hand screw rule.

Q.42. *If magnetic mono poles were to be there, how would one expect Gauss's law of magnetism to be modified?*

Ans. According to Gauss's law of magnetism, the flux of the magnetic field, through any closed surface is zero.

If magnetic monopoles were to exist, the flux of the magnetic field through a closed surface will be related to the net 'magnetic monopole strength enclosed by that closed surface. Gauss's law, for magnetism, would therefore, become very similar to its corresponding form in electrostatics.

Q.43. *Obtain an expression for the magnetic moment associated with the orbital motion of an electron.*

Ans. We know that the current is nothing but the rate of flow of charge (across a given cross section). If therefore, we consider an electron orbiting round a nucleus with a frequency n, we can say that a charge e (the charge of the electron) crosses any cross section (in the orbit) n times in one second. The charge crossing the cross section in one second or its equivalent current is, therefore,

$$I = ne$$

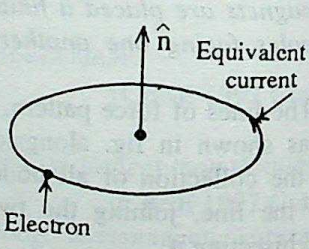
Now the magnetic moment μ associated with a current loop is IA, where A is the area of the loop. If therefore, r is the radius of the orbit, we have

$$\mu = IA = ne.\pi r^2$$

Now, $n = \frac{1}{T}$ and $T = \frac{2\pi r}{v}$

$$\therefore \quad \mu = ne\pi r^2 = \frac{1}{T} e\pi r^2 = e\pi r^2 \times \frac{v}{2\pi r} = \frac{1}{2} ver$$

or $$\mu = \frac{1}{2}\frac{e}{m}(mvr) = \frac{1}{2}\frac{e}{m} L,$$



where L (= mvr) is the angular momentum associated with the orbital motion of the electron.

As we shall see later, Bohr's theory tells us that L can only take values that are an integral multiple of $\frac{h}{2\pi}$ (h = Planck's constant = 6.62×10^{-34} J-s). Hence,

$$L = n\frac{h}{2\pi} \quad (n = 1, 2, 3, ...)$$

$$\mu = n\left(\frac{eh}{2\pi m}\right) = n\mu_B, \text{ where } \mu_B = \left(\frac{eh}{2\pi m}\right)$$

Q.44. *A vector needs three quantities for its specification. Name the three independent quantities conventionally used to specify the earth's magnetic field.*

Ans. The three independent quantities, commonly used for specifying earth's magnetic field, are

(i) angle of declination (ϕ) (ii) angle of dip (θ) (iii) horizontal component of earth's magnetic field (B_H)

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Q.45. *What is angle of declination?* (1)

Ans. The angle of declination is the angle between the geographic and the magnetic meridians at a given place.

Q.46. *Define horizontal component of earth's magnetic field?* (1)

Ans. The horizontal component of earth's magnetic field, at a given place, is the component of earth's magnetic field, along the horizontal direction, at that place.

Q.47. *Define angle of dip.* (1)

Ans. The angle of dip, at a given place, equals the angle between the direction of the earth's magnetic field at that place, with the horizontal direction there.

Q.48. *Name the elements of earth's magnetic field.* **(CBSE 1994) (1)**

Ans. Refer to answer no. 44 above.

Q.49. *Name the three magnetic elements of earth's field and explain their meaning.*

(CBSE 1993 Comptt. 1995) (3)

Ans. Refer to answer no. 44, 45, 46 above.

Q.50. *What is the value of dip at magnetic poles?* (1)

Ans. The value of the angle of dip, at the magnetic poles, is 90°.

Q.51. *What is the angle of dip at the equator?* (1)

Ans. The value of the angle of dip at the equator is 0°.

Q.52. *How does the angle of dip change as one moves from magnetic equator to the poles?* (2)

Ans. The angle of dip increases, from 0° to 90°, as one moves from the equator to the poles.

Q.53. *What is the value of the angle of dip at any place situated on the magnetic equator of the earth?*

(CBSE 1995) (1)

Ans. The value is 0°.

Q.54. *Define angle of dip of a given place. What is the value of the angle of dip at the equator?*

(CBSE 1994 Comptt.) (1)

Ans. Refer to answer no. 47 and 51 above.

Q.55. *If the horizontal and vertical components of earth's magnetic field at a place are equal, what is the angle of dip there?* **(CBSE 1993) (1)**

Ans. Let θ be the angle of dip at that place.

We than have $B \cos\theta = B \sin\theta$ or $\tan\theta = 1$

$\therefore$ $\theta = 45°$

Thus, the angle of dip at that place is 45°

Q.56. A small magnet is pivoted to move freely in the magnetic meridian. At what place, on the earth's surface, will the magnet be vertical? **(CBSE 1995) (1)**

Ans. The magnet will be vertical at the poles where the earth's magnetic field is totally in the vertical direction.

Q.57. *Define the terms magnetic declination and dip angle. The value of dip at a certain place in South India, is 20°. Will it more or less in England? Give reason for your answer.*

(CBSE 1995 Comptt.) (2)

Ans. Refer to answer no. 45 and 47 above for the definitions.

The value of the angle of dip would be more in England than its value in South India. This is because England is nearer to the poles than South India.

Q.58. What is the angle of dip at a place where the horizontal and vertical components of earth's field are equal to each other? **(CBSE 1995 Comptt.) (1)**

Ans. Refer to answer no. 55 above.

Q.59. Define the terms magnetic declination and dip angle. Value of dip at a place in South India is 18°. Will it more or less in England? **(CBSE 1993 Comptt.) (2)**

Ans. Refer to answers no. 45 and 47 for the definitions.

The value will be more in England as explained above in answer no. 57.

Q.60. *If you make a map of earth's magnetic field lines at Melbourne in Australia, would the lines seem to*

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Q.72. *How will you distinguish a diamagnetic substance from a paramagnetic substance?*

Ans. (i) A diamagnetic substance will be very feebly repelled by a magnetic field while a paramagnetic would get feebly attracted.

(ii) A diamagnetic substance, when freely suspended, would come to equilibrium in a direction norma that of the magnetic field in which it is present. A paramagnetic substance, on the other hand, would get alig parallel to the field.

Q.73. *Classify materials on the basis of their behaviour in a magnetic field. Under which category does come? How does the magnetic property of iron change with increase of temperature?*

(CBSE 1995)

Ans. Refer to answer no. 70 above for the required classification.

Iron is a ferromagnetic material. The magnetic properties of iron become less and less strong as temperature is increased. We express this by saying that iron tends to pass from a ferromagnetic state to paramagnetic one as its temperature is raised.

Q.74. *Distinguish between dia, para and ferromagnetic substances. Give one example of each.*

(CBSE 1994)

Ans. Refer to answer no. 70 above for the required distinction.

Example :

Diamagnetic : Bismuth

Paramagnetic : Aluminium

Ferromagnetic : Iron.

Q.75. *Distinguish between the fields* **B** *and* **H**. *Define magnetic permeability of a material.*

Ans. In real space, i.e., in the presence of any material medium, there is magnetic induction in the medi and, therefore, the medium produces additional field due to induced magnetism so that the resultant fie consists of :

(i) magnetic field intensity **H** (which is there even in the absence of any material medium); and

(ii) the field produced due to the induced magnetism in the medium.

This resultant field in the presence of any material medium is normally indicated by **B** and is called *magnetic induction vector* or *magnetic flux density*. The ratio of **B** to **H** measures the *permeability*, μ, of material.

$$\mu = \frac{\text{Flux density}}{\text{Magnetic field intensity}} \text{ or } \mu = \frac{\mathbf{B}}{\mathbf{H}}$$

From above it is obvious that in *free space* (since there is no induction) **B** *and* **H** *must be the same, i.e.,* permeability of free space must be unity. This is so in the CGS system of units. However, in the SI units, in space, we have

$\mathbf{B} = \mu_0 \mathbf{H}$, where $\mu_0 = 4\pi \times 10^{-7}$ henry/metre and is the permeability of free space. μ_0 is actually a constant proportionality in the SI units.

Q.76. *Define relative permeability.*

Ans. To compare the inductive properties of different materials a quantity called *relative permeability* is defined : It is the ratio of *the flux density produced in a material to the flux density produced in vacuum the same magnetising field.*

$$\mu_r = \left| \frac{\text{B (material)}}{\text{B (vacuum)}} \right| \text{ for same } \mathbf{H} = \frac{\mu \mathbf{H}}{\mu_0 \mathbf{H}} = \frac{\mu}{\mu_0}$$

The relative permeability of air is found to be very close to that of vacuum, *i.e.*, $\mu = \mu_0$. This indicates that *air is a very close approximation to free space.*

Q.77. *Give two examples of a diamagnetic substance.*

Ans. Bismuth, Copper (Cadmium, quartz).

Q.78. *Name two paramagnetic materials.*

Ans. Aluminium, Chromium (Platinum, Antimony)

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Q.79. *Name two ferromagnetic materials.* **(1)**

Ans. Iron, Nickel (Cobalt).

Q.80. *Why is a diamagnetic material repelled by a magnet and a paramagnetic material attracted by it?* **(3)**

Ans. The atoms/molecules of a diamagnetic material have no magnetic moment associated with them while those of a paramagnetic material have a non-zero magnetic moment. However, there is no net magnetic moment, for a physically small volume element, of either in the absence of an external magnetic field.

When a diamagnetic material is put in a magnetic field, there is an induced magnetic moment, in all the atoms/molecules that is antiparallel to the field direction. Because of this, a physically small volume element also acquire an induced magnetic moment antiparallel to the field direction and this causes it to be repelled by the magnetic field.

A paramagnetic material, when put in a magnetic field, has a torque exerted on its atomic molecular dipoles. The torque tends to align these dipoles parallel to the field so that a physically small volume element acquires an induced magnetic moment parallel to the field direction. This causes it to be attracted by the field.

Q.81. *Does the magnetisation of a paramagnetic salt depend on temperature?* **(1)**

Ans. Yes; the magnetisation of a paramagnetic salt is quite strongly affected by temperature.

Q.82. *Is μ_r greater than, less than or equal to 1 for a diamagnetic material?* **(1)**

Ans. The relative permeability, μ_r, of a diamagnetic material is less than unity.

Q.83. *Is magnetic susceptibility positive or negative for a diamagnetic material?* **(1)**

Ans. The magnetic susceptibility is negative for a diamagnetic material.

Q.84. *State Curie's law of paramagnetism.* **(CBSE 1997) (1)**

Ans. For paramagnetic materials, the magnetic susceptibility χ depends on temperature, It is inversely proportional to absolute temperature T of the material, *i.e.*,

$$\chi = C/T,$$

C is a constant known as Curie's constant and this results is known as *Curie's law.*

Q.85. *A paramagnetic rod is suspended in the region of a uniform magnetic field. In equilibrium what is the angle between the rod and the magnetic field?* **(1)**

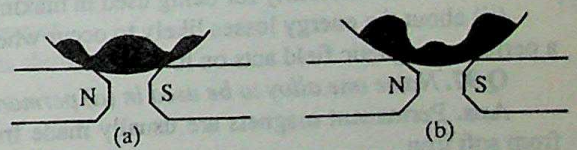
Ans. The angle is 0° as the paramagnetic rod would come to rest along the direction of the magnetic field.

Q.86. *Why is diamagnetism almost independent of temperature?* **(2)**

Ans. Diamagnetism is because of the induced magnetic moments (in its atom/molecules) in a direction antiparallel to that of the field. This induced magnetic moment is always produced in a direction antiparallel to the field irrespective of the location or random thermal energy of the atom/molecule. Hence, the diamagnetic behaviour turns out to be atmost independent of temperature.

Q.87. *A solution of chrome alum is poured in watch glass placed over two nearly (1 mm apart) pole pieces of a magnet. Draw and explain the shape of liquid. What happens if pole pieces are moved apart?* **(2)**

Ans. Chrome alum is paramagnetic in nature. Hence, it would tend to move from the region of weak field to that of the strong field.



When the pole pieces are very near to each other, the field in their centre is stronger than that at the edges. Hence, the solution will tend to move towards the centre. The shape acquired will thus, be as shown in (a) alongside.

When the pole pieces are normal far apart, the field in the middle becomes quite weak while that at the edges becomes stronger. The liquid thus, tends to move towards the edges and takes the shape shown in (b) above.

Q.88. *Sodium chloride solution contained in a watch glass is poured over two pole pieces of a magnet about 1 mm apart. Draw and explain the shape of the liquid. What happens when pole pieces are moved apart?* **(2)**

Ans. Sodium chloride solution is a diamagnetic one. Hence, its behaviour would be opposite to that of chrome alum.

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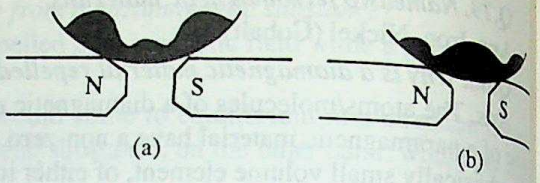
When the pole pieces are very close to each other, the field in the middle is stronger than that at the pole pieces themselves. On moving the pole pieces far apart, the field in their middle becomes much smaller than the field at the pole pieces themselves. Hence, the shape of the liquid in the two cases is as shown in Fig. (a) and (b) below.



(a) (b)

Q.89. *What is the order of magnitude of μ_r for ferromagnetic materials?*

Ans. The value of μ_r for ferromagnetics is quite large as much as nearly 2000 for iron.

Q.90. *Define Curie temperature for a ferromagnetic materials.*

Ans. The *Curie temperature* is a temperature of transition for ferromagnetic materials. These materials show a paramagnetic behaviour above this temperature. Below this temperature, however, their behaviour is ferromagnetic in nature.

Q.91. *Would the maximum possible magnetisation of a paramagnetic sample be of the same order of magnitude as the magnetisation of ferromagnetic material?*

Ans. Yes, in the limit of saturation, if attained, the two magnetisations would be of the same order.

Q.92. *Why are all pieces of iron not magnets even though iron is a ferromagnetic material?*

Ans. A piece of iron would become a magnet only if the 'magnetised domains', present in it, are arranged in an orderly way. By themselves, these domains are oriented in a completely random way. It is only when an external magnetising field is used that we get some order brought about in the otherwise random orientation of these domains. Hence, a piece of iron would behave like a magnet only after being 'treated' by a suitable magnetising field.

Q.93. *Give two points to compare the magnetic properties of steel and soft iron.*

Ans. Soft iron is not able to retain its magnetism after the magnetising field has been removed. Steel on the other hand, tends to retain its magnetism even after removal of the magnetising field.

Soft iron, once magnetised, needs a very small 'coercive force' to demagnetise it, steel on the other hand, is much more difficult to demagnetise.

Q.94. *In which direction would a compass needle align if taken to geographic (i) north (ii) south pole?*

Ans. It may align in any direction. **(CBSE 2000)**

Q.95. *What is hysteresis?*

Ans. The induced magnetisation, in a sample of a ferromagnetic material, tends to lag behind (in phase) the external magnetising field. We refer to this phenomenon as *hysteresis.*

Q.96. *What are the uses of knowing hysteresis curve?*

Ans. A knowledge of the hysteresis curve of a ferromagnetic material enable us to decide:

(i) about its suitability for being used in making permanent or electromagnets.

(ii) about the energy losses likely to occur when it is used as the core of a transformer or in a machine where a periodic magnetic field acts on it.

Q.97. *Name one alloy to be used in (a) permanent magnet (b) electromagnets.*

Ans. Permanent magnets are usually made from Cobalt steel, or tincal. Electromagnets are usually made from soft iron.

Q.98. *List the desired characteristics of a material used to make permanent magnets.*

Ans. A material used for making permanent magnets must have a

(i) high retentivity (ii) high coercive force (iii) wide hysteresis curve.

Q.99. *What are the desired characteristics of an electromagnet? Name a ferromagnetic alloy having the desired characteristics.*

Ans. A material, used for making an electromagnet, must have a

(i) low retentivity (ii) low coercive force

(iii) thin hysteresis curve.

Soft iron is a material that has these properties.

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Q.100. *List the important characteristics of the core of a transformer or choke. Name alloys having these characteristics.* **(2)**

Ans. The material used for making the core of a transformer, or choke, has to be constantly under the action of a periodic changing magnetic field. Hence, it must have as thin a hysteresis curve as possible. This also implies a low retentivity and a low coercivity. A material having these characteristics is soft iron. An alloy having these characteristics is *mu-metal.*

Q.101. *Can a ferromagnetic material be completely demagnetised?* **(1)**

Ans. Yes, a ferromagnetic material can be (almost) completely demagnetised by using (an oppositely directed) demagnetising field. It can also be demagnetised by raising its temperature or by hammering, etc.

Q.102. *Is the core of an electromagnet made of a hard or soft ferromagnetic material?* **(1)**

Ans. The core of an electromagnet is made of a soft ferromagnetic material.

Q.103. *State Curie-Weiss's law for ferromagnetics.* **(1)**

Ans. For ferromagnetic material, the magentic susceptibility χ depends strongly on temperature. Its variation is expressed by the relation $\chi = \frac{C}{T - T_0}$ C is a constant and T is the absolute temperature of the material. This equation is known as *Curie-Weiss law.*

Q.104. *What are ferrites? Give an example.* **(1)**

Ans. Ferrites are composite oxides of iron that are of semiconducting nature but have magnetic properties similar to that of iron.

Q.105. *What kind of ferromagnetic material is used for coating magnetic tapes in a cassette player or for building 'memory stores' in a modern computer?* **(1)**

Ans. We use 'ferrites' for this purpose. **(1)**

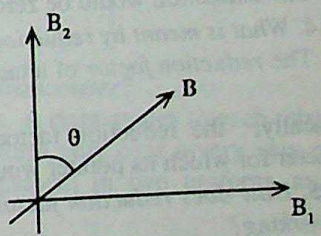
Q.106. *What is tangent law?*

Ans. When a magnet is suspended in a region of two uniform magnetic fields, at right angles to each other, it comes to rest along the direction of the resultant field.

Hence if this resultant field makes an angle θ with the field B_2, say, we have

$$B_2 = B\cos\theta \quad \text{and} \quad B_1 = B\sin\theta$$

$$\therefore \quad \frac{B_1}{B_2} = \tan\theta \quad \text{or} \quad B_1 = B_2\tan\theta$$



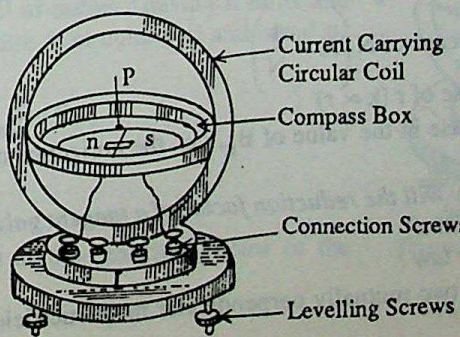
This result is known as the tangent law. **(1)**

Q.107. *What is the principle of a tangent galvanometer?*

Ans. The tangent galvanometer is based on the *tangent law* for its working. The two mutually perpendicular fields, used in it, are those due to the (i) earth and (ii) a current carrying circular coil. **(1)**

Q.108. *Draw a labelled diagram of a tangent galvanometer.*

Ans. The labelled diagram of a tangent galvanometer is shown below.



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Q.109. *What are the two fields acting on the small magnetic needle of a tangent galvanometer?*

Ans. The two fields are (i) the field of the earth (ii) the field of the current carrying circular coil.

Q.110. *Why do we use a pointer to read deflections of the magnetic needle of a tangent galvanometer?*

Ans. The magnetic needle has to be made very small so that our assumption, of its being in a uniform fie is justified. However, this makes it difficult to read the deflections of the needle. To overcome this difficulty long light (aluminium) pointer is attached to the needle.

Q.111. *State the factors on which the field at the centre of a circular coil depends.*

Ans. The field at the centre of a circular coil depends on

(i) the current through it

(ii) the radius of the coil

(iii) the permeability of the medium in which the coil is present.

and (iv) the number of turns in the coil.

Q.112. *How will the deflection in a tangent galvanometer change if the coil be displaced from magnet meridian?*

Ans. Let the coil be displaced through an angle α from the magnetic meridian. The component of the earth's field, at right angles to the field, would then be $BE \cos \alpha$.

Hence, the deflection θ would be given by

$$N \frac{\mu_0 I}{2r} = (B_E \cos \alpha) \tan \theta$$

$$\therefore \quad \tan \theta = N \frac{\mu_0 I}{2 r B_E \cos \alpha}$$

Thus, θ would be more than its true value.

Q.113. *What will be the deflection in a tangent galvanometer, if the plane of coil be placed at right angle to the magnetic meridian?*

Ans. The deflection would be zero as the two fields would now be parallel to each other.

Q.114. *What is meant by reduction factor of a tangent galvanometer? What is its physical significance?*

Ans. The *reduction factor* of a tangent galvanometer is the current needed to produce a deflection of 45° in it.

Physically, the reduction factor gives us the value of the current, in the circular coil of a tangent galvanometer for which its pointer would get deflection by 45°.

Q.115. *How does reduction factor vary with (a) the number of turns (b) the radius of the coil and (c) the place of working?*

Ans. We have, for a tangent galvanometer,

$$N \frac{\mu_0 I}{2r} = B_E \tan \theta \Rightarrow I = \left(\frac{2 r B_E}{\mu_0 N} \right) \tan \theta = k \tan \theta$$

Thus, $$k = \left(\frac{2 r B_E}{\mu_0 N} \right)$$

$\therefore$ (i) k decreases with an increase of N $\left(K \propto \frac{1}{N} \right)$

(ii) k increases with an increase of r ($k \propto r$)

(iii) k increases with an increase in the value of B_E, *i.e.*, the horizontal component of earth's magnetic field at the place of working. ($k \propto B_E$)

Q.116. *State tangent law. How will the reduction factor of a tangent galvanometer change when the number of turns of its coil is doubled? Explain?*

Ans. According to the *tangent law :*

(CBSE 1994)

When a magnet is situated in two mutually perpendicular magnetic fields $\mathbf{B}_1$ and $\mathbf{B}_2$, it comes to rest at an angle θ with the field $\mathbf{B}_1$ such that

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$B_2 = B_1 \tan\theta$, or $\theta = \tan^{-1}(B_2/B_1)$

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The *reduction factor*, k, of a tangent galvanometer is given by $k = \frac{2rB}{\mu_0 n}$

Thus, $k \propto (1/n)$. Hence, the reduction factor gets halved when the number of turns of its coil is doubled.

Q.117. *Why do we place the plane of the coil of the tangent galvanometer in the magnetic meridian?* **(2)**

Ans. We place the plane of the coil in the magnetic meridian so that the magnetic field, due to the current in it, is perpendicular to the earth's magnetic field. [The magnetic field of current carrying circular coil is normal to the plane of the coil.]

Q.118. *Why do we set the coil of the tangent galvanometer in the magnetic meridian and how is the accuracy of the adjustment tested?* **(3)**

Ans. Refer to answer no. 117 above for answer to the first part.

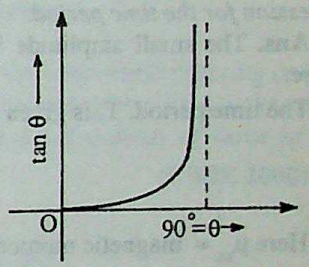
The accuracy of the adjustment is tested by reversing the current in the coil and observing the deflections in both the cases. The deflections would be *equal* if the coil is correctly set in the magnetic meridian.

Q.119. *Why do we take readings of deflection with current direct and reverse?*

Ans. We take readings both with the direct and the reverse current to make sure that the coil is correctly set in the magnetic meridian. If the two readings are not equal, we take their mean to minimize the error due to such an incorrect setting of the plane of the coil.

Q.120. *Why should the deflection be in the neighbourhood of 45° in a tangent galvanometer. Give reasons for your answer.* **(3)**

Ans. The tangent of an angle varies from 0 to ∞ as the angle change, from 0° to 90°. The change is very sharp beyond an angle of 60°.



If the deflection is very small (< 30°), the relative error in it $(\frac{\Delta\theta}{\theta})$ would be quite large. If the deflection is large (≥ 60°), a small error in its reading can cause a large change in the value of tan θ. Hence, the best range of deflections is from 30° to 60°. The mean of this range ($\theta = 45°$) is, therefore, the preferred value of the angle of deflection.

Q.121. *Why do we use a short needle in the compass box of a tangent galvanometer?* **(2)**

Ans. We want the compass needle to be subjected to two uniform fields, at right angles to each other. The earth's field is uniform over large regions while the coil's own field is uniform only over a very very narrow region. Hence, the needle must be very small to make sure that it is present in two uniform, mutually perpendicular, fields.

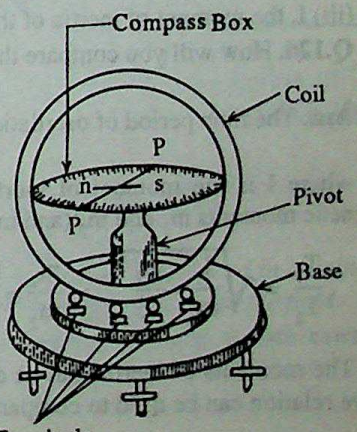
Q.122. *Discuss the principle, construction and working of a tangent galvanometer.* **(3)**

Ans. *Principle* : A freely suspended magnet in a region of two mutually perpendicular and uniform fields $\mathbf{B}_1$ and $\mathbf{B}_2$ in equilibrium makes an angle θ with field $\mathbf{B}_1$ such that $B_2 = B_1 \tan\theta$. In a tangent galvanometer the field $\mathbf{B}_1$ is the horizontal component of earth's field B_H. The *field* B_2 is due to a circular coil of radius r having n turns and carrying a curent I. B_2 is field at the centre of circular coil and equal μ_0 NI/2r. Therefore

$$(\mu_0 nI/2r) = B_H \tan\theta$$

or $$I = \left(\frac{2rB_H}{\mu_0 n}\right)\tan\theta = k\tan\theta,$$

where $k = 2r\,B_H / \mu_0 n$ and is known as the *reduction factor* of the tangent galvanometer.



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Construction : Fig. below shows the essentials of a tangent galvanometer. It consists of a stout horizon base provided with leveling screw. A vertical circular coil is mounted on the base and is free to rotate in vertical plane about an axis passing through its centre and perpendicular to the base. A deflection magnetome is mounted on a vertical pivot at the centre of vertical circular coil. The deflection magnetometer has a sma compass needle ns free to move in a horizontal plane. P. P. is a light aluminium pointer at right angle to ns. Th pointer moves against a graduated scale and is used to note the defection θ of the magnet.

Working : Level the base of galvanometer with levelling screw. The magnet ns is moving freely in horizontal plane and points in the direction of earth's magnetic field. The *vertical coil* is rotated till the plane coil is parallel to the compass needle ns. In other words the *plane of coil coincides with the magnetic meridia* The deflection magnetometer is rotated till pointer reads 0-0. The current to be measured is passed throu galvanometer selecting appropriate number of circular turns. The magnet, in equilibrium, turns through an ang θ which is read with the help of pointer. The current I, is

$$I = \left(\frac{2rB_H}{\mu_0 n}\right)\tan\theta$$

knowing, r, B_H n and θ, I is easily calculated.

Q.123. *Derive the relation between the current and the deflection produced in a tangent galvanometer.*

(CBSE 1993) (3

Ans. Refer to answer no. 122 above.

Q.124. *What is the nature of small amplitude horizontal oscillations of a freely suspended magnet? State th expression for the time period.* (2

Ans. The small amplitude horizontal oscillations, of a freely suspended magnet, are *simple harmonic* nature.

The time period, T, is given by

$$T = 2\pi\sqrt{\frac{I}{\mu_m B}}$$

Here μ_m = magnetic moment of the magnet

B = magnetic field in which the magnet is oscillating.

I = moment of inertia of the magnet about the axis around which it is oscillating.

Q.125. *On what factor does the period of a magnet depend when oscillating in a uniform field.* (1

Ans. The time period of a magnet, oscillating in a uniform field, depends on

(i) μ_m, the magnetic moment of the magnet

(ii) B, the magnetic field, in which the magnet is oscillating,

(iii) I, the moment of inertia of the magnet about the axis around which it is oscillating.

Q.126. How will you compare the magnetic moments of two bar magnets using a vibration magnetometer?

(CBSE 1993) (3

Ans. The time period of oscillations of a magnet of magnetic moment m is given by

$$T = 2\pi\sqrt{I/mB}$$

where I is the moment of inertia of the magnet about its suspension axis. Hence, for two magnets of magnetic moments m_1 and m_2 (and moments of inertia I_1 and I_2), we have

$$\frac{T_1}{T_2} = \sqrt{\frac{I_1}{m_1}\cdot\frac{m_2}{I_2}} \quad \therefore \frac{m_2}{m_2} = \left(\frac{T_1^2}{T_2^2}\cdot\frac{I_2}{I_1}\right)$$

The moments of inertia can be compared from the masses and dimensions of the two magnets. Hence, the above relation can be used to compare the magnetic moments of the two magnets.

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Q.127. *How can the magnetic moments of two bar magnets of same size and mass be compared using a vibration magnetometer?* **(CBSE 1997, 98) (2)**

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Ans. When two magnets are of same size and same mass their moments of inertia are equal. If T_1 and T_2 are their periods of vibration at a particular place then.

$$\frac{T_1}{T_2} = 2\pi \frac{\sqrt{\frac{I}{M_1 H}}}{2\pi\sqrt{\frac{I}{M_2 H}}} = \sqrt{\frac{M_2}{M_1}}$$

$$\Rightarrow \quad \frac{M_1}{M_2} = \frac{T_2^{\,2}}{T_1^{\,2}}$$

Q.128. *State the working principle of a tangent galvanometer. Write the mathematical expression for measuring currents using the tangent galvanometer.* **(CBSE 1998) (2)**

Ans. See answer to questions 107, 108 and 122.

Q.129. *Explain the principle of a tangent galvanometer. How does the reduction factor of the galvanometer change when (i) number of turns of the coil is increased and (ii) radius of the coil is decreased? Give reason for your answer in each case.* **(CBSE 1997) (3)**

Ans. See answer to question 107 for first part.

(i) When the number of turns of the coil is increased the reduction factor decreases.

(ii) When the radius of the coil is decreased, the reduction factor decreases.

Q.130. *State tangent law. Two tangent galvanometers have circular coils of the same radii, differing only in their number of turns. They are connected in series. When a steady current is passed in the circuit, the mean deflections in the galvanometers are Q_1, Q_2. Deduce an expression for the ratio of number of turns of the galvanometers.* **(CBSE 2000) (2)**

Ans. See answer to question 106 for first part

Current in the galvanometers are given by $I_1 = \frac{2rH}{\mu_0 N_1}\tan\theta_1$ and $I_2 = \frac{2rH}{\mu_0 N_2}\tan\theta_2$

For the galvanometers connected in series $I_1 = I_2$

$$\frac{2rH}{\mu_0 N_1}\tan\theta_1 = \frac{2rH}{\mu_0 N_2}\tan\theta_2 \Rightarrow \frac{\tan\theta_1}{N_1} = \frac{\tan\theta_2}{N_2} \Rightarrow \frac{N_1}{N_2} = \frac{\tan\theta_1}{\tan\theta_2}$$

SOLVED NUMERICAL PROBLEMS ON UNIT – V

Example 1. *What is the magnetic moment associated with a coil of one turn, area of cross section 10^{-4} m, carrying a current 2A?* **(CBSE 1993)**

Solution : The magnetic moment is given by

μ_m = number of turns × area of cross section of each turn × current.

$\therefore \quad \mu_m = 1 \times 10^{-4} \times 2 \text{ A–m}^2 = \mathbf{2 \times 10^{-4} \text{ A–m}^{-2}}$

Example 2. *A bar magnet of magnetic moment 6 A-m^2 has a length of 10 mm. It is placed in a uniform magnetic field of 0.5T. What is the torque acting on the magnet when it makes an angle of 30° with the field.*

Solution : The torque τ, acting on a magnet of magnetic moment μ making an angle θ with external magnetic field is $\tau = \mu B \sin\theta$

Given $\mu = 6 \text{ A} - \text{m}^2$; $B = 0.5$ T; $\theta = 30°$

$\therefore \tau = 6 \times 0.5 \times \sin 30 = 6 \times 0.5 \times 0.5 = \mathbf{1.5 \text{ N–m}}$

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Example 3. *A short bar magnet of magnetic moment 0.9 JT^{-1}, placed with its axis at 45° with a uniform external magnetic field, experiences a torque of magnitude 0.063J. Find the strength of the magnetic field.* **(CBSE 1994 Compt**

Solution : The torque, τ, experienced by a magnet of magnetic moment μ_m, kept at an angle θ to a uniform magnetic field B, is given by $\tau = \mu_m B \sin\theta \quad \therefore B = \dfrac{\tau}{(\mu_m \sin\theta)}$

Substituting values, we get $B = \dfrac{0.063\ J}{0.9\ JT^{-1} \times \sin 45^\circ} = \dfrac{0.063 \times \sqrt{2}}{0.9}\ T = \dfrac{0.09}{0.9}\ \mathbf{T = 0.1\ T.}$

Example 4. *A closely wound solenoid of 2000 turns and area of cross section $1.6 \times 10^{-4}\ m^2$, carrying a current of 4.0 A is suspended through its centre allowing it to turn in a horizontal plane. (a) What is the magnetic moment associated with the solenoid? (b) What are the force and torque on the solenoid if a uniform horizontal magnetic field of 7.5×10^{-2} T is set up at an angle of 30° with the axis of the solenoid.*

Solution : Let μ be the magnetic moment of solenoid. We know $\mu = nAI$. Given $n = 2000$; $A = 1.6 \times 10^{-4}\ m^2$; $I = 4A$. Therefore,

(a) $\mu = 2000 \times 1.6 \times 10^{-4} \times 4 = \mathbf{1.28\ Am^2}$.

(b) The net force on a magnet placed in a uniform magnetic field is *zero*. The torque τ is $\tau = \mu B \sin\theta$

$= 1.28 \times 7.5 \times 10^{-2} \times \sin 30^\circ$

$= 1.28 \times 7.5 \times 10^{-2} \times 0.5 = \mathbf{0.048\ N\text{–}m}$.

Example 5. *A bar magnet of magnetic moment 8 JT^{-1} is placed in a uniform magnetic field of 0.1 T. What is the energy stored in the magnet when it is turned through an angle of 45° ?*

Solution : The energy stored in a magnet when it is turned so as to make an angle θ with external magnetic field (B) is $\mu B\ [1 - \cos\theta]$, where μ is the magnetic moment of magnet.

Given $\mu = 8\ JT^{-1}$, $B = 0.1$ T, $\theta = 45^\circ$

$\therefore$ Energy stored $= 8 \times 0.1\ [1 - \cos 45^\circ]$ J

$= 8 \times 0.1 \times [1 - 0.7071] = 8 \times 0.1 \times 0.2929 = \mathbf{0.234\ J}$.

Example 6. *A bar magnet of magnetic moment 1.5 JT^{-1} is aligned with the direction of a uniform magnetic field of 0.22 T. (a) What is the amount of work required to turn the magnet so as to align its magnetic moment (i) normal to the field direction (ii) opposite to the field direction? (b) What is the torque on the magnet is cases (i) and (ii)?*

Solution : The work done (W) in turning a magnet of magnetic moment (μ) such that it makes an angle with an external magnetic field B is $W = \mu B\ [1 - \cos\theta]$

Given $\mu = 1.5\ JT^{-1}$; $B = 0.22$ T

(a) (i) When magnet is normal to field, $\theta = \pi/2$. Therefore,

$W_1 = 1.5 \times 0.22\ [1 - \cos \pi/2] = 1.5 \times 0.22 = \mathbf{0.33\ J}$

(ii) When magnet is opposite to magnetic field, $\theta = \pi$

$\therefore W_2 = 1.5 \times 0.22\ [1 - \cos \pi] = 2 \times 1.5 \times 0.22 = \mathbf{0.66\ J}$

(b) The torque τ on magnet is $\mu B \sin\theta$. Therefore,

(i) $\tau_1 = 1.5 \times 0.22 \times \sin \pi/2 = \mathbf{0.33\ J}$ and (ii) $\tau_2 = 1.5 \times 0.22 \times \sin \pi = \mathbf{zero}$

Example 7. *A short bar magnet of magnetic moment 0.9 J/T is placed with its axis at 45° to a uniform magnetic field. If it experiences a torque of 0.063 joule, (i) calculate the magnitude of the magnetic field and (ii) what orientation of the bar magnet corresponds to the stable equilibrium in the magnetic field.* **(CBSE 2000**

Solution: $\mu_m = 0.9\ J\ T^{-1}$, $\theta = 45^\circ$, $\tau = 0.063$ J

(i) We have $\tau = \mu_m B \sin\theta \Rightarrow B = \dfrac{\tau}{\mu_m \sin\theta} = \dfrac{0.063}{0.9 \times \dfrac{1}{\sqrt{2}}} = \mathbf{0.099\ T}$

(ii) The bar magnet will be in stable equilibrium when its magnetic moment is parallel to the magnetic field.

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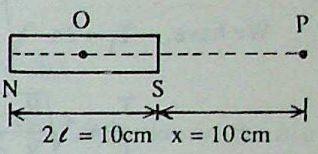
Example 8. *A neutral point is found on the prolongation of the axis of a bar magnet at a distance of 10 cm from one end. If the length of the magnet be 10 cm and* $B_E = 0.3$ *G. Find the magnetic moment of the magnet.*

Solution : Let P be the neutral point on the axis of bar magnet. The magnitude of field at P due to bar magnet and earth must be same. The field B at P due to bar magnet of magnetic moment μ is

$$B = \left(\frac{\mu_0}{4\pi}\right)\frac{(2\mu x)}{(x^2 - l^2)^2}.$$



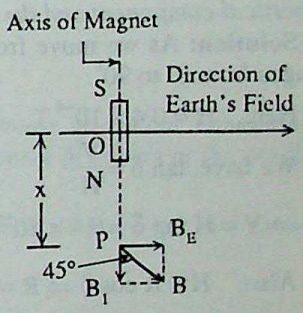
Also $B = B_E$.

Hence, $$0.3 \times 10^{-4} = \left(\frac{4\pi \times 10^{-7}}{4\pi}\right)\frac{2\mu \times 0.1}{[(0.1)^2 - (0.05)^2]^2}$$

or $$\mu = \frac{0.3 \times 10^4 \times (75 \times 10^{-4})^2}{2 \times 10^{-8}} = \mathbf{0.8437\ JT^{-1}}.$$

Example 9. *A short bar magnet of magnetic moment* 5.25×10^{-2} *jule per tesla is placed with its axis perpendicular to the earth's field direction. At what distance from the centre of the magnet on its axis the magnetic field is inclined at 45° with the earth's field? The magnitude of earth's field is 0.42 gauss.*

Solution : Fig. below shows the magnet NS with its axis at right angles to earth's field. P is a point on axis of the bar magnet where resultant magnetic field B makes an angle of 45° with earth's field. Let B_1 be magnetic field at P due to short bar magnet. Obviously $B = B_1$. Also $B_1 = \frac{\mu_0}{4\pi}\left(\frac{2\mu}{x^3}\right)$, where x is distance of P from mid-point of magnet NS



$$\therefore \quad \frac{\mu_0}{4\pi}\left(\frac{2\mu}{x^3}\right) = 0.42 \times 10^{-4}$$

or $$(10^{-7} \times 2 \times 5.25 \times 10^{-2})/x^3 = 0.42 \times 10^{-4}$$

$$\therefore \quad x = [(10.5 \times 10^{-9})/(0.42 \times 10^{-4})]^{1/3}$$

or $$x = (2.5 \times 10^{-6})^{1/3} = \mathbf{1.357 \times 10^{-2}\ m}.$$

Example 10. *A magnetic needle free to rotate in a vertical plane parallel to the magnetic meridian has the north tip pointing down at 18° with the horizontal. The magnitude of the horizontal component of the earth's field is 0.40 G. What is the magnitude of the earth's field at that place?*

Solution : The horizontal component B_H of earth's field at any place is $B_H = B \cos \delta$, where δ is the angle of dip and B is the earth's field.

Given $\delta = 18°$; $B_H = 0.4\ G = 0.4 \times 10^{-4}$ T.

Therefore, $B = B_H/\cos \delta = 0.4 \times 10^{-4} / \cos 18° = \frac{0.4 \times 10^{-4}}{0.9511} = \mathbf{0.421 \times 10^{-4}\ T}.$

Example 11. *Horizontal component of earth's magnetic field at a place is* $\sqrt{3}$ *times the vertical component. What is the value of angle of dip at this place?* **(CBSE 1997)**

or

The vertical component of earth's magnetic field at a place is $\frac{1}{\sqrt{3}}$ *times the horizontal component. What is the value of angle of dip at this place?* **(CBSE 1998)**

Solution: We have, $\tan \delta = \frac{V}{H}$

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$\Rightarrow \tan\delta = \frac{V}{\sqrt{3}\,V}$ $(\because H = \sqrt{3}\,V) \Rightarrow \tan\delta = \frac{1}{\sqrt{3}} \Rightarrow \delta = \mathbf{30^\circ}$.

Example 12. *A magnet oscillating in a horizontal plane, has a time period of 3 seconds at a place where angle of dip is 30° and 4 seconds at other place, where the dip is 60°. Compare the resultant magnetic fields the two places.* **(CBSE 1997 Comp**

Solution: Here, $T_1 = 3$ sec, $\delta_1 = 30^\circ$, $T_2 = 4$ sec. $\delta_2 = 60^\circ$

We have, $T_1 = 2\pi\sqrt{\frac{I}{MH_1}} = 2\pi\sqrt{\frac{I}{MR_1\cos\delta_1}}$ $T_2 = 2\pi\sqrt{\frac{I}{MH_2}} = 2\pi\sqrt{\frac{I}{MR_2\cos\delta_2}}$

$$\frac{T_1}{T_2} = \sqrt{\frac{R_2\cos\delta_2}{R_1\cos\delta_1}} \Rightarrow \frac{T_1^{\,2}}{T_2^{\,2}} = \frac{R_2\cos\delta_2}{R_1\cos\delta_1}$$

$$\Rightarrow \quad \frac{R_1}{R_2} = \frac{T_2^{\,2}\cos\delta_2}{T_1^{\,2}\cos\delta_1} = \frac{16\cdot\frac{1}{2}}{9\cdot\frac{\sqrt{3}}{2}} = \frac{8\times 2}{9\sqrt{3}} = 1.02$$

$\Rightarrow \quad R_1 : R_2 = \mathbf{1.02 : 1}$.

Example 13. *How does the angle of dip vary as one moves from the equator towards the north pole? If the horizontal component of earth's magnetic field at a place when the angle of dip is 60° is 0.4×10^{-4} T, calculate the vertical component and the resultant magnetic field of earth that at point.* **(CBSE 1997 Compt**

Solution: As we move from magnetic equator towards magnetic north pole of the earth, the angle of dip changes from 0° to 90°.

Here, $H = 0.4\times10^{-4}$ T, $\delta = 60^\circ$

We have, $\tan\delta = \frac{V}{H}$

$\Rightarrow V = H\tan\delta = 0.4\times10^{-4}\times\tan 60^\circ = 0.4\times\sqrt{3}\times10^{-4} = \mathbf{6.8\times10^{-5}\ T}$

Also, $H = R\cos\delta \Rightarrow R = \frac{H}{\cos\delta} = \frac{0.4\times10^{-4}}{\cos 60^\circ} = \frac{0.4\times10^{-4}\times 2}{1} = \mathbf{0.8\times10^{-4}\ T}$.

Example 14. *The ratio of horizontal component of earth's magnetic field to the resultant magnetic field at a place is $\frac{1}{\sqrt{2}}$. What is the angle of dip at that place?*

(CBSE 2000

Solution: We have $\frac{H}{R} = \frac{1}{\sqrt{2}}$

$\Rightarrow \quad \frac{R\cos\delta}{R} = \frac{1}{\sqrt{2}}$ $(\because H = R\cos\delta)$

$\Rightarrow \quad \cos\delta = \frac{1}{\sqrt{2}} \Rightarrow \delta = \mathbf{45^\circ}$.

Example 15. *What is the angle of dip at a place where the horizontal and vertical components of earth's magnetic field are equal?*

(CBSE 2000

Solution: We have, $\tan\delta = \frac{V}{H} = 1 \Rightarrow \delta = \mathbf{45^\circ}$.

Example 16. *A magnet is suspended in the region of two uniform and mutually perpendicular fields. In equilibrium the magnet makes an angle of 60° with the field of strength 0.2 T. What is the magnitude of the other field?*

Solution : According to the tangent law $B_2 = B_1\tan\theta$, where θ is the angle which magnet makes with field B_1. Given $B_1 = 0.2$ T, $\theta = 60^\circ$; therefore , $B_2 = 0.2\times\tan 60 = 0.2\times1.732 = \mathbf{0.346\ T}$.

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Example 17. *A tangent galvanometer having 20 turns of coil of radius 2 mm is placed at a place, where* $\delta = 20°$ *and the total intensity of earth's field is 0.4 T. What is reduction factor of galvanometer?*

Solution : The reduction factor (k) of a tangent galvanometer is $2rB_E/\mu_0\, n$, where B_E is the horizontal component of earth's field. Let B and δ denote the total intensity of earth's field and the angle of dip. Then

$$B_E = B\cos\delta = 0.4\cos 20° = 0.4 \times 0.9399 = 0.3758\ T$$

Also, $r = 2 \times 10^{-3}$ m and $n = 20$

$$\therefore \quad k = \frac{2 \times 2 \times 10^{-3} \times 0.3758}{4\pi \times 10^{-7} \times 20} = 0.1503/25 \times 10^{-6} = 6 \times 10 = \mathbf{60A}.$$

Example 18. *Two tangent galvanometers P and Q are connected in series. The deflection in the two galvanometers is 20° and 47.5° respectively. What is the ratio of turns in the two galvanometers? Assume radius of coils of the two galvanometers to be same.*

Solution : Since the galvanometers are connected in series current, (i) in both is the same. Let r be the common radius of coils of both galvanometers, n_1 n_2 is the number of turns in galvanometer P and Q respectively. We have,

$$I = \left(\frac{2rB_E}{\mu_0 n_1}\right)\tan 20° = \left(\frac{2rB_E}{\mu_0 n_2}\right)\tan 47.5°$$

or $0.3639/n_1 = 1.091/n_2$

or $$\frac{n_1}{n_2} = \frac{0.3639}{1.0913} = 1/3 \ \therefore\ n_1 : n_2 :: 1 : 3$$

Example 19. *A magnetic needle pivoted at its centre of mass and free to rotate in a plane containing a uniform field of 100 G is displaced and oscillates with frequency 1.5* s^{-1}. *If the moment of inertia of the needle is* 0.75×10^{-6} *kg* m^2, *9 determine the magnetic moment of the needle.*

Solution : The time-period (T) of a magnet of moment of inertia (I), magnetic moment (μ) in a external magnetic field (B) is $T = 2\pi\sqrt{I/\mu B}$

Given, $T = I/v = \left(\frac{1}{1.5}\right)$ s, $J = 0.75 \times 10^{-6}$ kg m^2, $B = 100 \times 10^{-4}$ T

$$\therefore \quad \frac{1}{1.5} = \frac{2}{3.142}\left(\frac{0.75 \times 10^{-6}}{\mu \times 10^{-2}}\right)^{1/2}$$

or $$\mu = \frac{(1.5)^2 \times 4 \times 0.75 \times 10^{-6}}{(3.142)^2} = \mathbf{0.684 \times 10^{-6}\ JT^{-1}}.$$

Example 20. *Compare the moment of inertia of two magnets that oscillate with time periods of 2s and 3s respectively in the same uniform magnetic field. The magnetic moments of the two magnets are in the ratio 1 : 1.1.*

Solution : We have, $T_1 = 2\pi\sqrt{\frac{I_1}{\mu_{m_1} B}}$ and $T_2 = 2\pi\sqrt{\frac{I_2}{\mu_{m_2} B}}$

$$\therefore \quad \frac{T_1^2}{T_2^2} = \frac{I_1}{I_2}\ \frac{\mu_{m_2}}{\mu_{m_1}}$$

$$\therefore \quad \frac{4}{9} = \frac{I_1}{I_2} \times \frac{1.1}{1.0}$$

$$\therefore \quad \frac{I_1}{I_2} = \frac{4}{9} \times \frac{1}{1.1} = \frac{4}{9.9}.$$

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UNIT - VI

ELECTROMAGNETIC INDUCTION AND ALTERNATING CURRENTS

CBSE SYLLABUS CONTENTS

Induced e.m.f., Faraday's law. Lenz's law, electromagnetic induction, self and mutual inductance, alternating currents, impedance and reactance, power in A.C. circuits with L, C and R. Series circuit (Phasor diagram), resonant circuit. Electrical machines and devices — transformer, A.C. generator, choke and starter.

No. of periods allotted : 18 out of 168

No. of marks allotted : 8 out of 70.

UNIT – VI A : ELECTROMAGNETIC INDUCTION

BASIC FACTS AND FORMULAE

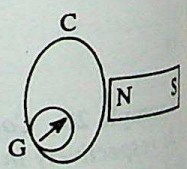
Electromagnetic Induction

Faraday as a result of a series of experiments was able to show that it is possible to produce an electric current from a magnetic field. The phenomenon is known as electromagnetic induction.

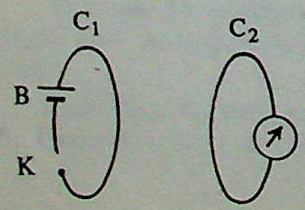
Faraday's studies have brought about a revolution in the uses of electricity and its production and we often hear the remark : *'Had there been no Faraday (Meaning really his discovery of the phenomenon of electromagnetic induction), there would have been neither electricity nor all the benefits and uses that have come from a proper and judicious use of this wonderful form of energy.*

Faraday's Experiments

Consider a coil C connected with a galvanometer and a bar magnet NS placed close to it. If there is no relative motion between the coil and the magnet the galvanometer G indicates no current in the coil. On moving the magnet towards the coil the galvanometer shows a deflection. This indicates the generation of an e.m.f. between the terminals of C connected across the galvanometer G. The deflection presists so long as there is relative motion between C and the magnet. If the magnet is moved away from the coil the same results are obtained excepting that the direction of deflection in the galvanometer reverses.



Consider two coils C_1 and C_2 placed close to each other. The coil C_1 is connected to a battery B through a key K and a galvanometer G is connected to coil C_2. If there is no current in coil C_1, or a steady current is flowing, there is no deflection in the galvanometer G. However, if there is no current in coil C_1, and a current is established by closing the key K, the current takes a time of about 10^{-3} s to acquire its steady value as given by Ohm's law. During this time of 10^{-3}s, the current in coil C_1 is changing and there is a deflection in galvanometer connected to C_2. In case the steady current flowing in C_1 is made to die out by opening the key K, the galvanometer G again shows a deflection. The direction of deflection now is opposite to the one observed earlier.



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Faraday's Laws of Electromagnetic Induction

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Faraday's law states that when the magnetic flux through a circuit is changing, an induced e.m.f. is set up which lasts as long as the change of flux exists. The magnitude of this induced e.m.f. at any instant is proportional to the negative rate at which the flux through the circuit is changing.

We may state *Faraday's laws* in a more explicit way, as follows :

(1) *Whenever there is a change in the normal magnetic flux linked with a circuit, an induced e.m.f. lasts so long as the change is taking place.*

(2) *The magnitude of the induced e.m.f. is proportional to the time rate of change of magnetic flux, i.e.,*

$$|e| \propto \frac{d\phi}{dt}$$

where |e| is the magnitude of induced e.m.f. and $\frac{d\phi}{dt}$ is the time rate of charge of the magnetic flux linked with the circuit under consideration.

Lenz's Law

Lenz's law gives the direction of the induced e.m.f. It states that *the induced current will appear in such a direction that it opposes the change that produced it.*

It follows from Lenz's law that the agent causing the magnet to move either towards or away from the coil will always experience a resisting force. It will, therefore, have to do work. It is this work that is getting converted into 'electrical energy' in the form of the induced e.m.f.

The complete Mathematical Statement of the Law of Electromagnetic Induction

Lenz's law is taken into account in Faraday's law of electromagnetic induction by rewriting Faraday's second law as

$$e = -\frac{d\phi}{dt}$$

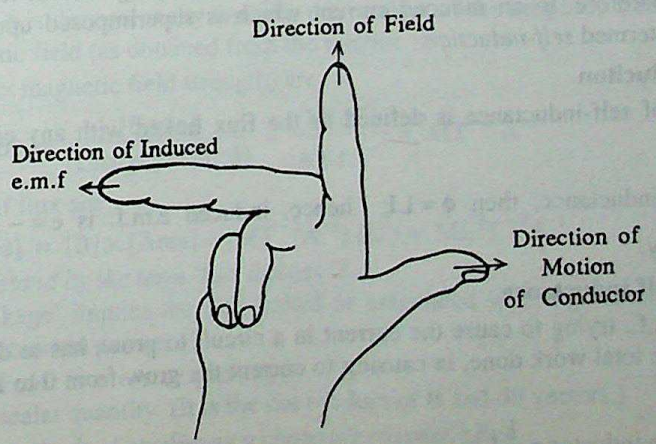
The above equation can also be expressed in vector notation

To do this we note that by definition

$$e = \int \mathbf{E}.d\boldsymbol{l}$$

Fleming's Right Hand Rule

The direction of induced e.m.f. is given conveniently in terms of Fleming's right-hand rule : When the thumb, the first and centre finger of right hand are extended at right angles to each other, then if the first finger represents the direction of the field and the thumb the direction of motion, the second finger will point in the direction of the current.



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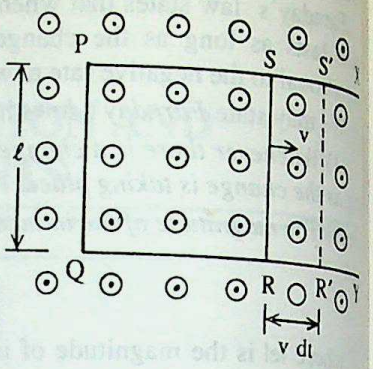
Motional e.m.f.

Whenever a conductor is moved with a uniform speed in the region of uniform magnetic field an induced e.m.f. is produced across its ends. This induced e.m.f. is known as motional e.m.f.



In Fig. above a uniform magnetic field B exists perpendicular to the plane of page and directed towards reader. PX and QM are rails over which conductor RS moves with a uniform speed v. There is no friction between the rails and wire RS. Let RS and R′S′ be the position of moving wire at t = t and t = $t + dt$ respectively. Let ϕ and $\phi + d\phi$ be the magnetic flux linked with circuit at t and t + dt. Obviously,

$$\phi = [\text{area PQRS}] \times B \text{ and}$$

$$\phi + d\phi = [\text{area PQR'S'}] \times B$$

$$d\phi = [\text{area PQR'S'} - \text{area PQRS}] \times B = [\text{area RR'SS'}] \times B = l \times vdt \times B$$

Let |e| be the magnitude of motional e.m.f. From Faraday law

$$|e| = \frac{d\phi}{dt} = Blvdt/dt = Blv$$

Eddy Current

The induced current produced in a circuit due to change of magnetic flux linked with it is known as *eddy current.* For example (i) The current produced in the coil of a galvanometer as it moves in the magnetic field pole pieces is an eddy current. (ii) A metallic block is placed in the region having a varying magnetic field. The induced current produced in metallic block is the eddy current. (iii) The metalllic bob of a pendulum clock made to oscillate in the magnetic field due to a magnet. Due to induced eddy current the bob of pendulum stop after executing a few oscillations. When the bob is slotted, the induced eddy current decreases and the number oscillations made by the bob increase.

Electromagnetic Damping

Whenever a conductor or coil moves in a uniform magnetic field, there is an induced e.m.f. in the conductor or coil. If the coil or conductor is in a complete circuit there is an induced current. According to Lenz's law the induced current opposses the cause of its production. The cause of induced e.m.f. is the motion of the coil conductor. The induced current opposses and arrests the motion of the conductor or coil. This is electromagnetic damping.

Self Induction

The change of magnetic field which takes place due to a varying current in any circuit gives rise to an induced e.m.f. and, therefore, to an induced current which is superimposed upon the original current. This property of a circuit is termed *self-induction.*

Coefficient of Self Induciton

The co-efficient of self-inductance is defined as the flux linked with any circuit when a unit current is flowing thorough it.

If L is the self-inductance, then $\phi = LI$; hence, induced e.m.f. is $e = -L\frac{dI}{dt}$. The practical unit of self-inductance is henry.

Energy Stored in a Self Inductance

The source of e.m.f., trying to cause the current in a circuit to grow, has to do work against the opposing self-induced e.m.f. The total work done, in causing to current the grow from 0 to I, is $(1/2)\ LI^2$. Hence, we may say :

$$\text{Energy stored in an inductor} = \frac{1}{2} LI^2$$

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If $I = 1$, we have, $W = \frac{1}{2} L$ or $L = 2W$

We may hence say, the coefficient of self-inductance is also equal to twice the work done in establishing the magnetic flux associated with a unit current in the circuit.

Phenomenon of Mutual Induction

In general whenever two coils are in the same neighbourhood, a part of the flux produced by a current in one coil will cut through the other coil and a changing current in the first circuit, will induce an e.m.f. in the second coil. The phenomenon is called mutual induction.

Coefficient of Mutual Inductance

The coefficient of mutual inductance of two coils is defined as the magnetic flux associated with one of the coils when the other is traversed by a unit current.

A Reciprocity Relation for the Coefficient of Mutual Inductance

The mutual inductance is same irrespective of which coil is considered first, *i.e.*,

$$M_{12} = M_{21} = M$$

This result is known as reciprocity relation.

Factors Affecting Self Inductance and Mutual Inductance

The self inductance of a coil or the mutual inductance of a pair of coils

(i) is a constant for the coil or the pair of coils.

(ii) depends on the geometry of the coil / coil pair, *i.e.*, on the shape, size, etc.

(iii) depends on the number of turns in the coil / each member of the pair of coils.

(iv) nature of the medium, in which the coil/pair of coils, is/are present.

SUBJECTIVE QUESTIONS ON UNIT – VIA

Q.1. *Define magnetic flux.* (1)

Ans. The magnetic flux ϕ, linked with a circuit or a surface, equals the number of lines of force passing normally through it.

We define the magnetic flux (ϕ) through the equation.

$$\phi = \int_S \mathbf{B} \cdot d\mathbf{S}$$

where the integration is to be carried over the area S of the circuit or the surface considered.

Physically, we may interpret the magnetic flux as the *'rate of flow'* of the magnetic field through it.

Q.2. *What are the dimensions of magnetic flux?* (1)

Ans. The magnetic flux ϕ is dimensionally equal to the product of the magnetic field and the area. Further, the dimensions of the magnetic field (as obtained from the relation :

|force| = charge × speed × magnetic field strength) are

$$[B] = \frac{[\text{Force}]}{[\text{Charge}]\,[\text{Speed}]} = \frac{MLT^{-2}}{AT\,LT^{-1}} = MT^{-2}A^{-1}$$

Hence, the dimensions of flux are

$$[\phi] = [B] \times [\text{Area}] = (MT^{-2}A^{-1})(L^2) = ML^2T^{-2}A^{-1}$$

Q.3. *What do you understand by the term 'flux linkage'?* (1)

Ans. The term 'flux linkage' implies the flux linked or associated with a given surface. Its definition is, therefore, the same as given above in answer (1).

Q.4. *Is magnetic flux a scalar or a vector quantity?* (1)

Ans. Magnetic flux is a scalar quantity. (It is the dot product of **B** and **dS** vectors.)

Q.5. *Name the different methods of producing a changing magnetic flux.* (2)

Ans. We can change the magnetic flux linked with a given circuit, or a coil, or a surface, by

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(i) producing a relative motion between a magnet and the given circuit (or coil, or surface).

(ii) keeping the circuit (or coil, or surface) near another coil or circuit through which a changing curre flowing.

(iii) moving a metallic conductor normally to the direction of a uniform magnetic field.

Q.6. *A flat coil of wire, the ends of which are connected to sensitive galvanometer is (i) moved up towa the north end of a long bar magnet (ii) threaded on the bar magnet (iii) moved along a bar magnet (iv) remo to a far off distance. What indication does the galvanometer give during these operations?*

Ans. (i) The galvanometer will show a deflection because the magnetic flux, linked with the coil, will b on changing during its motion.

(ii) The galvanometer will not show any deflection. This is because the coil, 'threaded' on the bar magne now a part of the magnet and there can be no relative motion between the two. Hence, there would be no cha in the flux linked with the coil.

(iii) When the coil is moved along a bar magnet, there would be a change in the flux linked with it a hence, the galvanometer will show a deflection. [The 'magnetism' of a bar magnet is strongest at its two e (the two 'poles') and almost *zero* at its centre].

(iv) When the coil is taken far away from the magnet, there would be (practically) no magnetic field du the bar magnet at its location. Hence, the flux linked at any instant would remain 'zero' (almost) for all positi of the coil. There being no change in flux, the galvanometer will not show any deflection.

Q.7. *What is electromagnetic induction?*

Ans. The phenomenon of production of an induced e.m.f. in a coil (or a circuit), due to a change in t magnetic flux linked with it, is known as the phenomenon of electromagnetic induction.

Q.8. *State Faraday's laws of electromagnetic induction.*

Ans. According to Faraday's laws of electromagnetic induction :

(i) An induced e.m.f. is set up in a coil (or a circuit) only if there is a change in the magnetic flux link with it.

(ii) The induced e.m.f. lasts only as long as the magnetic flux (linked with the coil circuit) keeps changing.

(iii) The magnitude of the induced e.m.f. equals the rate of change of the magnetic flux linked with coil/circuit.

These laws were supplemented by another law, due to Lenz, which tells us about the direction of induced e.m.f. According to Lenz's law :

The direction of the induced e.m.f. is always such as to oppose the very cause to which it is due.

We express all these results in a neat and compact form through the mathematical equation :

$$e = -\frac{d\phi}{dt}$$

Lenz law is based on the law of conservation of energy.

Q.9. *State Faraday's law of electromagnetic induction. Express it mathematically.*

(CBSE 1993 Comptt. 1995)

Ans. Refer to answer no. 8 above.

Q.10. *State Fleming's right hand rule.*

Ans. According to Fleming's right hand rule :

Stretch the thumb, the first finger and centre finger of right hand so that they are mutually perpendicular one another. Let the first finger point in the direction of magnetic field, the thumb, the direction of motion conductor, then the centre finger points in the direction of induced current.

Q.11. *State Lenz's law. On which law of conservation is it based?* **(CBSE 1996, 1999)**

Ans. Refer to the last part of answer no. 8 above.

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Q.12. *What factors govern the magnitude of the induced e.m.f. in a coil rotated in a magnetic field.*

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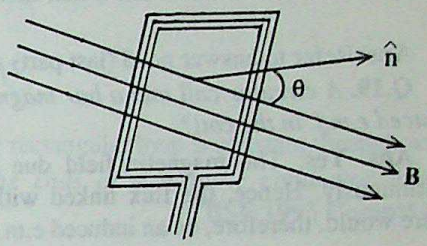
(3)

Ans. The magnitude of the induced e.m.f. depends on the rate of change of the magnetic flux linked with the coil. Now the flux linked with a coil of area A, having N turns, and kept in a uniform magnetic field B, is

$$\phi = NAB \cos\theta$$

$$\therefore \quad e = -\frac{d\phi}{dt} = NAB \frac{d\theta}{dt} \sin\theta$$

$$= NAB\ \omega \sin(\omega t)$$



where $\omega = \frac{d\theta}{dt}$ = angular velocity of the coil.

Hence, the instantaneous induced e.m.f. will depend on.

(i) N, the number of turns in the coil.

(ii) A, the area of the coil.

(iii) B, the magnetic field in which the coil is present.

(iv) ω, the angular velocity of the coil.

(v) t, the time instant considered.

Q.13. *How would you show that a change in the number of lines of magnetic force, how so ever produced, threading through a circuit produces an induced e.m.f.* **(3)**

Ans. Whenever the number of the magnetic lines of force, threading a circuit, changes (through any means whatsoever), the flux linked with the circuit is changing. Hence, there is an induced e.m.f., as per Faraday's law. We can illustrate this experimentally by

(i) moving a magnet towards or away from a stationary coil.

(ii) moving a coil towards or away from a stationary magnet.

(iii) changing the current in a coil or circuit kept near the observational (experimental) coil.

(iv) rotating a coil in a uniform magnetic field.

(v) moving a conducting rod normally to the direction of a uniform magnetic field.

In all these cases, the magnetic flux linked with the coil is changing. Hence, there is an induced e.m.f. in the coil.

Q.14. *State the laws of electromagnetic induction and describe experiments you would perform to illustrate the factors which determine the magnitude of the induced currents set up in a closed circuit.* **(3)**

Ans. Refer to answer no. 8 for the statement of the *laws.*

We may do any of the experiments listed above in answer no. 13 above. We will observe that in all the cases, we will get a greater induced e.m.f. if the

(i) speed of motion of the coil rod, or rate of change of current in the neighbouring coil, or the speed of rotation of the coil, is increased.

(iii) area of the coil, the number of turns in it, the strength of the magnetic field are increased. [Such an increase brings about an increase in the instantaneous magnetic flux linked with coil].

Q.15. *A vertical metallic pole falls down through the plane of the magnetic meridian. Will any e.m.f. be produced between its ends? Give reason for your answer.* **(CBSE 1995 Comptt.) (1)**

Ans. When a vertical metallic pole falls vertically down through the plane of the magnetic meridian, it is falling *along* the earth's magnetic field. The flux 'linked' with it is, thus, zero throughout. Hence, there would be *no induced e.m.f.* across the ends of the pole.

Q.16. *A bar magnet falls from height 'h' through a metal ring. Will its acceleration be equal to 'g'? Give reason for your answer.* **(2)**

Ans. No; the acceleration will be always less than 'g'. The 'fall' of the magnet will cause an induced e.m.f. to be set up in the ring which will *always* oppose the 'fall' of the ring. (This will be so, as per Lenz's law, both when the magnet is above the ring, and when it is below the ring). The 'opposition' due to this induced e.m.f. will, therefore, cause the magnet to fall with an acceleration less than 'g'.

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Q.17. *Explain how Lenz's law is in accordance with the law of conservation of energy?* (2

Ans. Lenz's law is in accordance with the law of conservation of energy. This is because, if the induced e.m.f. were to *support* the cause to which it is due, we would keep on getting an induced e.m.f. *always* after just once initiating an initial change. This would imply, getting, energy continuously without any 'input'. This being obviously against the law of conservation of energy, we should have the induced e.m.f. always opposing the cause to which it is due. This is what Lenz's law states.

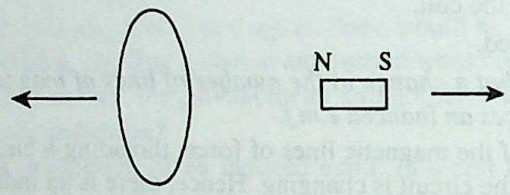
Q.18. *State Lenz's law. Show that Lenz's law follows from principle of conservation of energy.* (2

(CBSE 1995 Compt.

Ans. Refer to answer no. 8 (last part) and to answer no. 17 above.

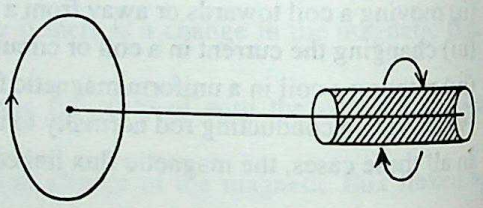
Q.19. *A circular coil and a bar magnet recedes from each other with the same velocity. Will there be an induced e.m.f. in the coil?* (1

Ans. Yes; The magnetic field due to the bar magnet at the location of the coil will be decreasing continuously. Hence, the flux linked with the coil will be decreasing (and hence, 'changing') continuously. There would, therefore, be an induced e.m.f. set up in the coil.



Q.20. *A small cylindrical bar is kept along the axis of a circular coil. Will there be any induced e.m.f. in the coil when the magnet is rotated about its axis?* (1)

Ans. No, there would be no induced e.m.f. This is because the magnetic field of the circular coil is along its axis. The cylindrical bar is, thus, lying with its axis along the direction of the magnetic field. A rotation of the cylindrical bar, about its own axis, will not, therefore, change the flux linked with it. Hence, no induced e.m.f. will be produced in it.



Q.21. *A conducting loop is held stationary normal to the field between NS poles of a fixed permanent magnet. By choosing a magnet sufficiently strong, can we hope to generate current in the loop?* (1)

Ans. No, there would not be any induced e.m.f. as there is no *change* in the magnetic flux linked with the coil.

Note : [Using a stronger magnet would only increase the flux linked with the coil. However, an induced e.m.f. is set up only if there is a change in the flux].

Q.22. *A closed conducting loop moves normally to the electric field between the plates of a large capacitor. Is a current induced in the loop when it is (i) wholly inside the capacitor? (ii) partially outside the plates of the capacitor? The electric field is normal to the plane of the loop.* (1)

Ans. No, there is no induced e.m.f. here. We are talking here of the flux of the *electric field* and an induced e.m.f. is produced only when the magnetic flux linked with the coil changes.

Q.23. *A rectangular loop and a circular loop move out of a uniform magnetic field region to a field free region with a constant velocity. In which loop should we expect the induced e.m.f. to be constant during their passage through the field region. The field is normal to the loop.* (2)

Ans. The induced e.m.f. will be zero (and hence, 'constant') through both the loops during their passage through the uniform field region. This is because the flux linked with them remains constant throughout their passage through the uniform field region. There being no change in the flux, the induced e.m.f. will be zero.

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Q.24. *A rectangular loop PQRS moves inside a perpendicular uniform magnetic field as shown in figure below. What is the induced e.m.f.?*

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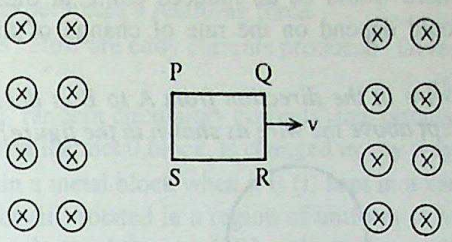


Ans. The induced e.m.f. would be *zero* as the flux linked with the rectangular loop is constant throughout.

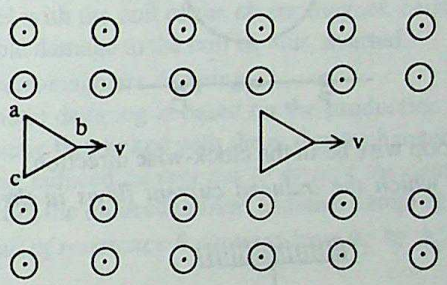
Q.25. *Give the expression for the e.m.f. induced between the ends of a metallic conductor moving perpendicular to a uniform magnetic field.* **(CBSE 1993 Comptt.) (1)**

Ans. The induced e.m.f. e is given by $|e| = Blv$,

where B = uniform magnetic field present, l = length of the conductor and v = its velocity along the direction perpendicular to **B**.

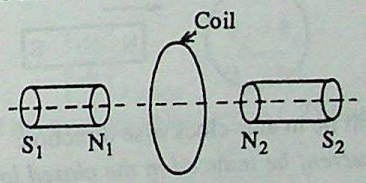
The complete vectorial expression is $e = \mathbf{B}.(\mathbf{l} \times \mathbf{v})$.

Q.26. *Figure below shows two positions of a loop abc in a perpendicular uniform magnetic field. In which position of coil is there an induced e.m.f.?*



Ans. There is no induced e.m.f. in either position as the *flux* linked with the loop is constant throughout.

Q.27. *In figure below N_1S_1 and N_2S_2 are identical magnets. Magnet N_1S_1 is moved away from the coil with a speed v. Magnet N_2S_2 moves towards the coil with same speed v. Is there any induced e.m.f. in the coil?*



Ans. No, there would be no induced e.m.f. in the coil. The decrease in the flux linked with it due to the '*away*' motion of the magnet N_1S_1 would be compensated by the '*towards*' motion of the magnet N_2S_2. The total flux linked with the coil, thus, remains constant throughout. Hence, there is no induced e.m.f.

Q.28. *When the motor of an electric refrigerator starts, the lights in the house become dim momentarily. Why?* **(1)**

Ans. When the motor of the refrigerator starts, it draws a (relatively large) current from the mains. Because of this, sudden change, an induced e.m.f. is set up which opposes the e.m.f. of the mains. There is thus a fall in the net e.m.f. and, hence, a sudden 'dimming' of the lights in the house.

Q.29. *A square loop is inside a uniform magnetic field as shown in figure. What is the induced e.m.f.? What is induced e.m.f. if the coil enters into or moves away from the region of magnetic field?* **(2)**

Ans. The induced e.m.f. is zero as long as the loop stays inside the uniform field.

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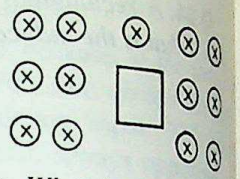
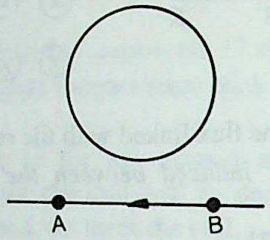
When the loop enters into or moves away from the region of the uniform magnetic field, there is a sudden change (in the flux linked with the loop) at the instant of its entry or exit. Hence, there would be an induced e.m.f. at these instants, the magnitude of which would depend on the rate of change of the magnetic flux (linked with the loop).



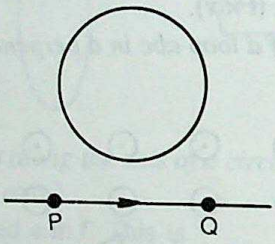
Q.30. *The electric current in a wire in the direction from A to B is decreasing. What is the direction of induced current in the metallic loop kept above the wire as shown in the figure?*



(CBSE 1997, 1999)

Ans. Induced current in the loop will be in the clock-wise direction.

Q.31. *The current through the wire PQ is increasing. In which direction does the induced current flow in the closed loop?*

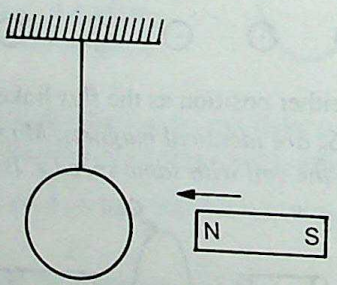


(CBSE 1997 Comptt.)

Ans. Induced current in the loop wire be in the clock-wise direction.

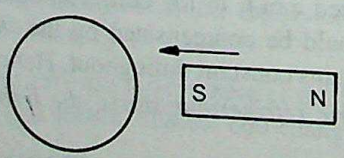
Q.32. *Give the direction in which the induced current flows in the wire loop, when the magnet moves towards it as shown in the figure.*

(CBSE 1997 Comptt.)



Ans. Induced current in the loop will be in anti-clockwise direction.

Q.33. *In which direction will the current be induced in the closed loop, if the magnet is moved as shown in the figure?*



(CBSE 1999)

Ans. Induced current in the loop will be in clock-wise direction.

Q.34. *An iron bar falling vertically through the hollow region of a thick cylindrical shell made of copper experiences a retarding force. What can we conclude about the iron bar?*

Ans. The iron bar must be a magnet. When a magnet falls through a hollow metal shell, it causes a change in the magnetic flux linked with the metal. This results in an induced e.m.f. which has to oppose the cause of

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which it is due. The cause, in this case, is the 'fall' of the magnet through the shell. Since the induced e.m.f. opposes this 'cause', the magnet experiences a retarding force.

Q.35. What are eddy currents? How are eddy currents produced? Give two applications of eddy currents.

(CBSE 1994 Comptt, CBSE 1993) (3)

Ans. Eddy currents are those 'random circulatory currents' that circulate within the volume of a metal block when the magnetic flux, linked with the metal block, is changed in any way whatsoever.

Eddy currents are produced in a metal block when it is (i) kept in a varying magnetic field; or (ii) moved in a varying magnetic field region or (iii) rotated in a region of uniform or varying magnetic field. These induced currents circulate throughout the volume of the metal. We refer to them as eddy currents because of their random 'circulatory' nature.

We may mention the following as applications of eddy currents :

(i) *Electromagnetic damping* : This is used for example, in the ordinary 'dead beat' type of moving coil galvanometers used in the laboratory.

(ii) *Induction heating* : The heating effects associated with eddy currents, have been used, among others, to prepare some alloys by heating the constituents in vacuum.

Q.36. *A small resistor (say a lamp) is usually put in parallel to the current carrying coil of an electromagnet. What purpose does it serve?* **(2)**

Ans. We have a fairly large induced e.m.f. in an electromagnet at the instant it is switched on or off. The heating, associated with the resulting (large) induced current, may damage the coil of the electromagnet. The presence of a small resistor, in parallel with the coil of the electromagnet, causes most of the induced current to flow through this resistor. Any, possible damage to the coil is, thus, averted.

Q.37. *Explain the principle of electromagnetic damping.* **(2)**

Ans. The process of electromagnetic damping is based on the production of an induced e.m.f. in a coil (or circuit or metal block) when the magnetic flux linked with the coil gets changed due to its rotation or motion in a region of magnetic field. The resulting induced current has *to oppose the cause to which it is due.* The 'cause' being the motion (or rotation) of the coil, the induced current causes a damping of the motion.

Q.38. *The flux linked with a circuit of resistance R changes from* ϕ_1 *to* ϕ_2. *What is the charge moving in the circuit?*

Ans. We have change in flux $= \phi_2 - \phi_1$

If ϕ_1 and ϕ_2 are the flux values at times t_1 and t_2 respectively, we have the average value of the rate of change of flux as

$$\left|\frac{d\phi}{dt}\right|_{Average} = \frac{\phi_2 - \phi_1}{(t_2 - t_1)}$$

This is, therefore, the magnitude of the average induced e.m.f. The average induced current is, therefore,

$$I_{Average} = \frac{1}{R} \cdot \frac{(\phi_2 - \phi_1)}{(t_2 - t_1)}$$

Since this average current flows for a time inerval $(t_2 - t_1)$, the total charge flowing is

$$Q = I_{Average} \times (t_2 - t_1) = \frac{1}{R} \cdot \left(\frac{\phi_2 - \phi_1}{t_2 - t_1}\right) \cdot (t_2 - t_1) = \left(\frac{\phi_2 - \phi_1}{R}\right)$$

Thus, total charge flowing $= \dfrac{\text{change in flux}}{\text{resistance of the circuit}}$

Q.39. *Two coils are placed nearby. One coil is connected to a battery and key. On pressing the key a current is established in the first coil. Is any current produced in second coil?* **(1)**

Ans. Yes; there would be a very short duration (or transient) current in the second coil at the instant the battery key of the first coil's circuit is pressed. (This is because of the sudden change in flux in the second coil which results in the production of an induced e.m.f. in it).

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Q.40. *Define coefficient of self inductance.*

Ans. The coefficient of self inductance of a given coil may be defined as either (i) the flux linked with it to a unit current in itself.

or (ii) the induced e.m.f. set up when the current in itself in changing at a unit rate.

Q.41. *What are the dimensions of self inductance?*

Ans. The coefficient of self inductance (L) is defined through the equation.

$$e = -L\frac{dI}{dt}$$

Now, e (= induced e.m.f.), is dimensionally equivalent to work per unit charge.

Hence, $$\frac{\text{work}}{\text{charge}} = [L]\left[\frac{\text{current}}{\text{time}}\right]$$

$$\therefore \quad [L] = \frac{\text{work} \times \text{time}}{\text{charge} \times \text{current}} = \frac{\text{work} \times \text{time}}{(\text{current} \times \text{time}) \times \text{current}} = \frac{\text{work}}{(\text{current})^2} = \frac{ML^2T^{-2}}{A^2} = ML^2T^{-2}A^{-2}$$

Q.42. *Define the term self inductance. Write its S.I. unit. Give two factors on which self inductance of an air cored coil depends.* **(CBSE 1995)** (2)

Ans. Refer to answer no. 40.

The SI unit of self inductance is the *henry* (H). A coil is said to have a self inductance of one henry if an e.m.f. of one volt gets induced in it when the current in it is changing at the rate of one ampere per second.

OR

A coil is said to have an inductance of one henry if the flux linked with it is one weber when a current of one ampere flows through it.

Self-inductance of a coil depends upon:

(i) its geometry i.e., its shape and size (ii) the number of turns on it.

Q.43. *Define the terms 'self induction' and 'self inductance'. Give its units. Write two factors on which the self inductance of (an air cored) coil depends.* **(CBSE 1993, CBSE 1993 Comptt.)** (3)

Ans. The phenomenon of 'self induction' refers to the e.m.f. induced in a coil due to a change in current in the coil itself.

The *self inductance* a coil equals the e.m.f. induced in it when the current through it is changing at a unit rate. (The self inductance of a coil equals the flux linked with it due to a unit current in itself).

The unit of self inductance is the *henry*. The self inductance of a (air cored) coil depends on:

(i) its *geometry i.e.*, its shape and area of cross section and (ii) the number of turns in it. (For a non-air cored coil, the self inductance depends very much on the nature of the medium 'enclosed' by the coil).

Q.44. *A choke coil and a bulb are connected in series to a d.c. source. The bulb shines brightly. How does its brightness change when an iron core is inserted in the choke coil?* **(CBSE 1995)** (2)

Ans. When an iron core is inserted in the choke coil, there is a sudden increase in its self inductance and, hence, a sudden increase in the flux linked with it. Hence, there is a sudden (very short duration) large induced e.m.f. which opposes the e.m.f. of the main source. Hence, the bulb will *get dim* at that instant. [Soon things become steady and the bulb would then regain its brightness].

Q.45. *Is it correct to say that self inductance plays the same role in an electric circuit as is the role of inertia in mechanics?* (1)

Ans. Yes; self inductance opposes changes in the current in the circuit in much the same may as inertia opposes changes in the state of motion of a particle in mechanics.

Q.46. *Show that the coefficient of self inductance of a circuit is equal to twice the work done in establishing the magnetic flux associated with a unit current in the circuit.* (2)

Ans. Let a source of e.m.f. be used to increase the current in a circuit from 0 to I, 'finally' estabalishing the current (in a time τ) at the value I. Let I be the current in the circuit at any instant t where $0 < t < \tau$. The induced e.m.f. of this instant would be

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$$e = -L\frac{dI}{dt}$$

For a time dt, around this instant, the source will have to do work against this induced e.m.f. The total charge transferred in this time being Idt, the work done would be

$$dW = |e|\,[I\,dt] = L\frac{di}{dt}\,I\,dt$$

$$= LI\,dI$$

$\therefore$ The total work done during the increase of current from 0 to I would, therefore, be

$$W = dW = L\int_0^I IdI = L\left|\frac{I^2}{2}\right|_0^I = \frac{L}{2}[I^2 - 0^2] = \frac{1}{2}LI^2$$

$$\therefore \qquad L = \frac{2W}{I^2}$$

Hence, if I = 1 ampere, L = 2W. Hence, the coefficient of self inductance is equal to twice the work done in establishing the magnetic flux associated with a unit current in the circuit.

Q.47. *Prove that the total energy stored in an inductor is* $\frac{1}{2}LI_{max}^2$, *where* I_{max} *is the maximum current through the inductor.* **(CBSE 1993) (2)**

Ans. Refer to answer no. 46 above.

Q.48. *A coil and a bulb are connected in series with a 6 volt d.c. source. A soft iron core is then inserted in the coil. What will happen to the intensity of the bulb?* **(1)**

Ans. Refer to answer no. 44 above.

Q.49. *Why, when an electric circuit is completed, the current does not reach its maximum value all of a sudden?* **(2)**

Ans. This is because of the self inductance of the circuit. The self inductance tends to oppose the growth of current in the circuit. The applied external e.m.f. has to do work against this opposition. Hence, it is only after some time that the current is able to (almost) reach its full expected steady value. The more the self inductance of the circuit, the larger is this delay.

Q.50. *A coil of insulated wire is connected in series with a bulb, a battery and a switch. When the circuit is completed, the bulb lights up immediately. The current is switched off and a rod of soft iron is placed inside the coil. What will be the behaviour of the bulb, when the circuit is completed now?* **(2)**

Ans. With the insertion of the iron rod, the self inductance of the coil increases considerably. This causes a noticeable delay in the growth of the current to its full steady value. The bulb will, therefore, be very dimly lighted at first. With time, its glow will increase and it would be only after sometime (or a few second, may be) that it would now glow with its full light.

Q.51. *A choke coil in series with a lamp is connected to a d.c. line. The lamp is seen to shine brightly. Insertion of an iron core in the choke cause no change in the lamp's brightness. Predict the corresponding observation, if the connection is to be in an a.c. line.* **(2)**

Ans. When the current in the circuit is already at its steady value, a change in the self inductance (caused by insertion of the iron rod in the coil) does not cause any induced e.m.f. to be developed, since the e.m.f. source is a d.c. one. Hence, there is no change in the brightness of the lamp.

When, however, the connection is to an a.c. line, a self inductance acts as an impedance whose value is ωL (ω = angular frequency of the applied a.c. and L= self inductance of the coil). Hence, the insertion of the iron rod (which causes L to increase) would increase the impedance of the circuit. The lamp would, therefore, dim down considerably.

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Q.52. *Calculate self inductance of a small-sized circular coil having n turns.*

Ans. A small sized circular coil, having n turns, produces a magnetic field, normal to the plane of the coil whose magnitude (at its centre) is n. μ_0 I/2a (a = radius of the coil). Hence, the total flux linked with the n turns would be $nA.\left[\frac{n\ \mu_0 I}{2a}\right] = \frac{n^2\mu_0 A}{2a} I$, where A is the area of each turn. We, thus, have

$$\phi = \frac{n^2\mu_0 I}{2a}\ I$$

But, $\phi = LI$, where L is the self inductance of the coil. Hence,

$$L = \frac{n^2\mu_0 I}{2a}$$

Q.53. *Obtain an expression for self inductance of a straight long solenoid.*

Ans. The axial magnetic field of a long straight solenoid has a magnitude, $B = \mu_0 nI$, where n = no. of turns per unit length of the solenoid. If r is the radius of the solenoid, the area of each turn is πr^2 and, hence, the total flux linked with a unit length of the solenoid is

$$\phi = (n\cdot\pi r^2)\cdot B = (n\cdot\pi r^2)\cdot n\cdot\mu_0 I = \mu_0\pi\, n^2\, r^2 I$$

But, $\phi = LI$. Hence, $L = \mu_0\pi\, n^2\, r^2$

This is the expression for the self inductance of a unit length of the solenoid.

Q.54. *Define coefficient of mutual inductance.*

Ans. The mutual inductance of a pair of coils can be defined as either (i) the flux linked with one of them when a unit current flows through the other. (ii) the e.m.f. induced in one of them when the current in the other is changing at a unit rate.

Q.55. *Name two factors on which the mutual inductance between a pair of coil depends.*

Ans. The mutual inductance of a pair of coils depends on

(i) their geometry (*i.e.*, their shape, size, number of turns, etc.).

(ii) the distance of separation between them.

(iii) the nature of the medium in which the coils are present.

Q.56. *Define mutual inductance. Write its S.I. unit. Give two factors on which the coefficient of mutual inductance between a pair of coil depends.*

Ans. Refer to answer no. 54 and 55 above. **(CBSE 1995)** (2)

The unit of mutual inductance is the *henry*.

Q.57. *A secondary coil of N turns of wire is wound on the middle of the primary coil of a solenoid of length l and radius r and number of turns per unit length n. What is the mutual inductance between the coils?* (2)

Ans. The number of turns per unit length of the primary of the solenoid is n. Hence, the (axial) magnetic field due to it is $B = \mu_0 n I$

The area of each turn is πr^2. Hence, the total flux, linked with the N turns is

$$\phi = N\cdot\pi r^2\cdot B = \mu_0\cdot\pi r^2\,\frac{N}{l}\,nI$$

But, $\phi = MI$. Hence, $M = \mu_0\cdot\pi r^2\ \frac{nN}{l}\ I$

Q.58. *Define the coefficient of self-inductance. Write its units. Give two factors on which the self-inductance of a long solenoid depends.*

Ans. The coefficient of self-inductance is defined as the flux linked with any circuit when a unit current is flowing through it. **(CBSE 1997 Comptt.)** (2)

The practical unit of self-inductance is henry.

The self-inductance of a long solenoid depends upon:

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(i) geometry of the solenoid, i.e. its shape, size etc.

(ii) nature of medium in which the solenoid is present.

Q.59. *If the number of turns of a solenoid is doubled, keeping the other factors constant, how does the self-inductance of the solenoid change?* **(CBSE 2000) (1)**

Ans. It increases four times because $L \propto N^2$.

Q.60. *How does the mutual inductance of a pair of coils change when:*

(i) the distance between the coils is increased?

(ii) the number of turns in each coil is decreased?

Justify your answer in each case. **(CBSE 1998) (2)**

Ans. (i) The mutual inductance of a pair of coils is dcereased when the distance between them is increased.

(ii) The mutual inductance of a pair of coils is decreased when the number of turns in each coil is decreased.

Q.61. *Two rings of radii R and r are arranged parallel to each other a distance x apart on their common axis (R > r). The mutual inductance of the bigger ring with respect to the smaller rings is M. What would be the mutual inductance of the smaller ring with respect to the bigger ring?* **(1)**

Ans. The mutual inductance of a pair of coils is a characteristic constant for the pair, *i.e.*, $M_{21} = M_{12}$.

Hence, the mutual inductance of the smaller ring with respect to the bigger one would also be M.

Q.62. *N_s turns of a secondary coil are wound over the N_p turns of the primary of a straight solenoid. What is the mutual inductance of the two coils?* **(2)**

Ans. The magnetic field due to the current in the primary is $B = \mu_0 \frac{N_p}{l} I$

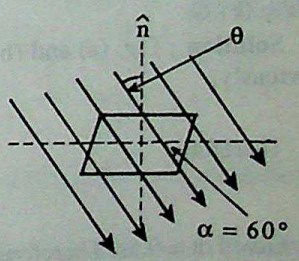
where l is the length of the solenoid. Hence, the total flux linked with the N_s turns of the secondary is

$$\phi = N_S \cdot (\pi r^2)\, B = \mu_0 N_P N_S \cdot \frac{\pi r^2}{l} I$$

But $\phi = MI$. Hence, $M = \mu_0 \dfrac{N_P N_S \pi r^2}{l}$

SOLVED NUMERICAL PROBLEMS ON UNIT – VI A

Example 1. *Fig. alongside shows a rectangular coil 2 cm × 4 cm placed in a uniform magnetic field B = 0.1 T. The field makes an angle of 60° with the plane of coil. What is the magnetic flux linked with the rectangular coil?*



Solution : Let θ be the angle between the normal to the area and the magnetic field B. The magnetic flux $\phi = AB \cos\theta = \left(\frac{\pi}{2}\right) - 60 = 30°$,

Also $A = 8 \times 10^{-4}\ m^2$; $B = 0.1\ T$

$\therefore \quad \phi = 8 \times 10^{-4} \times 0.1 \times \cos 30°$

$= 8 \times 10^{-5} \times (\sqrt{3}/2) = 8 \times 10^{-5} \times 0.866 = \mathbf{6.93 \times 10^{-5}\ T\text{-}m^2}$

Example 2. *A rectangular coil of cross-sectional area 100 cm^2 having 200 turns is placed with its plane at right angles to a uniform magnetic field 0.2 T. The magnetic field increases to 0.4 T in 0.1 s. What is the average induced e.m.f. in the coil?*

Solution : ϕ_i = The initial flux linked with coil = $nAB_i = 200 \times 100 \times 10^{-4} \times 0.2 = 4 \times 10^{-1}$ Wb

ϕ_f = The final flux linked with coil = $nAB_f = 200 \times 100 \times 10^{-4} \times 0.4 = 8 \times 10^{-1}$ Wb

$\therefore \quad e = -\frac{d\phi}{dt} = -\frac{4 \times 10^{-1}}{0.1} = -4V.$

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Example 3. *A rectangular coil of cross-sectional area 4 cm^2 is having 500 turns. The coil is placed in region having perpendicular uniform magnetic field of 0.2 T. The coil is pulled out of the region of magnetic field in 0.1 s. What is average induced e.m.f. in coil?*

Solution : According to Faraday's law, $e = \dfrac{-d\phi}{dt}$

The initial flux $\phi_i = nAB = 500 \times 4 \times 10^{-4} \times 0.2 = 4 \times 10^{-2}$ Wb

Since finally the coil is in a region having no magnetic field, $\varphi_f = 0$. Therefore,

$$d\phi = \phi_f = \phi_i = 0 - 4 \times 10^{-2} = -4 \times 10^{-2} \text{ Wb}$$

Also, dt = 0.1s.

Hence, $e = -\left(\dfrac{-4 \times 10^{-2}}{0.1}\right) = 4 \times 10^{-1}$ V = **0.4 V.**

Example 4. *A 28 turns coil, with average diameter of 0.02 m, is placed perpendicular to a magnetic field 8000 T. If the magnetic field changes to 3000 T in 4 s, what is the magnitude of the induced e.m.f.?*

(CBSE 1994 Comp

Solution : The area of each turn = $\pi r^2 = \pi \times \left(\dfrac{0.02}{2}\right)^2 \text{m}^2 = \pi \times 10^{-4} \text{ m}^2 = \dfrac{22}{7} \times 10^{-4} \text{ m}^2$

$\therefore$ Flux linked with all the 28 turns in a magnetic field B is

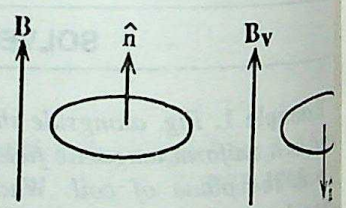
$$= 28 \times \frac{22}{7} \times 10^{-4} \text{ B weber} = 88 \times 10^{-4} \text{ B weber}$$

Hence, rate of change of flux (under given conditions)

$$= \frac{[88 \times 10^{-4} \times 3000 - 88 \times 10^{-4} \times 8000]}{4} = -11 \text{ Wb } s^{-1}$$

$\therefore$ Induced e.m.f. = $\dfrac{-d\phi}{dt} = 11$ V.

Example 5. *A coil of 1000 turns having a radius of 0.1 m is kept horizontally on a table. The coil is turned through 180° in 0.5 s. What is the average induced e.m.f. in coil? Given, vertical component of earth's field = 0.4 G.*



Solution : Fig. (a) and (b) show the initial and final position of coil. Obviously,

Therefore, $\phi_i = nAB_v$ and $\phi_f = -nAB_v$

$$d\phi = \phi_f - \phi_i = -2nAB_v$$

$$= -2 \times 10^3 \times \pi \times (0.1)^2 \times 0.4 \times 10^{-4} = -25.136 \times 10^{-4} \text{ Wb}$$

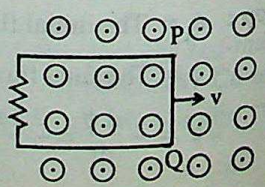
Given dt = 0.5s. Therefore, $e = -\dfrac{d\phi}{dt} = \dfrac{25.136 \times 10^{-4}}{0.5} = 50.272 \times 10^{-4}$ V = **5.03 mV.**

Example 6. *A bar 0.5 m long is moved with a uniform speed 10 ms^{-1} in a region of perpendicular magnetic field, of magnitude 0.2 Wb m^{-2}. What is e.m.f. generated in the bar? The ends of bar are connected to an external circuit. The total resistance of circuit is 1 Ω. What is the power expended in the circuit?*

Solution : Let PQ be bar moving in a magnetic field as shown in Fig. Iel the magnitude of induced e.m.f. in rod PQ is $|e| = Blv = 0.2 \times 0.5 \times 10$ V = 1 V

The power p consumed in the external circuit is $|e|^2/R$. Therefore,

$$p = |e|^2/R = (1)^2/1 = \mathbf{1\ W}.$$



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Example 7. *A rod of length 0.5 m is rotated with a uniform angular speed of 60 r.p.m. in a region having a uniform, perpendicular magnetic field 0.5 T. What is induced e.m.f. across the ends of rod?*

Solution : The induced e.m.f. $|e| = (1/2)\, Bl^2\, \omega$.

Given $B = 0.5$ T, $l = 0.5$ m; $\omega = 60$ r.p.s. $= 1$ r.p.s. $= 2\pi$ rad s^{-1}

$$\therefore |e| = \left(\frac{1}{2}\right) \times (0.5)^2 \times (2\pi)\ \text{V} = \mathbf{0.393\ V}.$$

Example 8. *A circular coil of radius 8 cm and 20 turns rotates about is vertical diameter with an angular speed of 50 rad s^{-1} in a uniform magnetic field of magnitude 3×10^{-2} T. What is the maximum induced e.m.f. in the coil?*

Solution : When a coil of n turns, having cross-sectional area A rotates with a speed ω in a uniform magnetic field, the maximum induced e.m.f. $e_0 = nAB\omega$

$$= 20 \times 3.142 \times (8 \times 10^{-2})^2 \times 3 \times 10^{-2} \times 50 = \mathbf{0.603\ V}.$$

Example 9. *A circular coil of cross-sectional area 50 cm^2 having 500 turns is at right angles to a uniform magnetic field of 0.2 T. The coil is connected to a galvanometer and rotates through 180° in 0.1 s. If resistance of coil and galvanometer is 40Ω. What is charge passing through galvanometer?*

Solution : The charge q passing through galvanometer is $q = (\phi_2 - \phi_1)/R$ Where ϕ_1 and ϕ_2 denote the initial and final flux through coil. Obviously, $\phi_1 = nAB$ and $\phi_2 = -nAB$

$$\therefore |q| = 2nAB/R = \frac{2 \times 500 \times 50 \times 10^{-4} \times 0.2}{40} = 25 \times 10^{-3}\ \text{C} = \mathbf{25\ mC}.$$

Example 10. *The induced e.m.f. in a coil is 5 V when current in coil changes at the rate of 25 As^{-1}. What is self-inductance of coil?*

Solution : We know, induced e.m.f. in a self-inductance is $|e| = L \dfrac{dI}{dt}$

Given $|e|$ 5V; $\dfrac{dI}{dt} = 25\ As^{-1}$ $\quad\therefore L = \dfrac{|e|}{\frac{dI}{dt}} = \dfrac{5}{25} = \mathbf{0.2H}.$

Example 11. *Magnetic flux of 5 microweber is linked with a coil when a current of 1 mA flows through it. What is the self inductance of the coil?* **(CBSE 1993)**

Solution : We have $\phi = LI$

$$\therefore 5 \times 10^{-6} = L \times 1 \times 10^{-3}$$

Hence, $L = 5 \times 10^{-3}$ henry $= \mathbf{5\ mH}$.

Example 12. *The self inductance of a coil of 500 turns is 100 mH. What will be self-inductance if number of turns is increased to 750 without any other change?*

Solution : We know that $L \propto n^2$, where n is the number of turns and L the self-inductance. Therefore, $\dfrac{L_1}{L_2} = \dfrac{n_1^{\,2}}{n_2^{\,2}}$ or $L_2 = \dfrac{n_2^{\,2} L_1}{n_1^{\,2}}$. Given $L_1 = 100$ mH; $n_1 = 500$; $n_2 = 750$

$$\therefore L_2 = 100 \times (750)^2/(500)^2\ \text{mH} = \mathbf{225\ mH}.$$

Example 13. *Mutual inductance of two coils is 8 mH. The current in one coil change at the rate of 0.1 kA/s. What is induced e.m.f. in the other coil?*

Solution : The induced e.m.f. $|e|$ in second coil when current in first coil changes at a rate $\dfrac{dI}{dt}$ is $M \dfrac{dI}{dt}$.

Given $M = 8\text{mH} = 8 \times 10^{-3}$ H; $\dfrac{dI}{dt} = 0.1$ KA/s $= 100\ As^{-1}$

$$\therefore |e| = 8 \times 10^{-3} \times 10^2 = \mathbf{0.8\ V}.$$

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Example 14. *Two coils P and Q are magnetically linked with one another. The average induced e.m.f. in is 900 V when current in P changes from 10 to 40 A in 10 ms. What is mutual inductance of the two coils? number of turns in both coils is doubled, what is their mutual inductance?*

Solution : We know $|e| = M\frac{dI}{dt}$.

Given $|e| = 900$ V; $dI = (40 - 10) = 30$ A; $dt = 10$ ms $= 10^{-2}$ s $\quad \therefore M = 900 / (30 / 10^{-2}) = 0.3$ H

The mutual inductance is proportional to product of number of turns in primary and secondary. Wh number of turns in both is doubled mutual inductance will be 4 times. Therefore,

$$M' = 4\ M = \mathbf{1.2\ H.}$$

Example 15. *The primary and secondary of a transformer has a mutual inductance of 0.5 H. What induced e.m.f. in secondary when current in primary changes at 5 As^{-1}?*

Solution : Let $|e_s|$ be the magnitude of induced e.m.f. in secondary when current in primary change at $\frac{dI}{dt}$

Then, $|e_s| = M\frac{dI_1}{dt} = 0.5 \times 5 = \mathbf{2.5\ V.}$

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BASIC FACTS AND FORMULAE

The Transformer

The transformer is a device for converting a power source from say a high voltage, low current supply to a low voltage high current source without appreciable loss of power. To a good approximation, the voltage between input and output of the transformer is given by the ratio of turns in the input and output windings

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

Energy Losses in a Transformer

In an actual transformer the output power is always less than the input power. The loss in power is due to :

(i) Lddy current losses, (ii) hysteresis losses, and (iii) joule heat losses.

The A.C. Dynamo

A.C. dynamo uses a closely wound rectangular coil which is made to rotate in a magnetic field about an axis perpendicular to the field. The magnetic flux it cuts is variable, and hence, the e.m.f. produced is in the form

$$E = E_{max} \sin \alpha$$

By using a splitting commutator a current can be produced which is always in the same direction.

The Choke Coil

The choke coil is simply an inductive coil made of a large number of turns of a reasonably thick copper wire wound on a ferromagnetic core. It, thus, has a large self inductance but a very low resistance. It is an LR circuit but can be approximated to a pure inductance. It can, therefore, be used to limit the current in an A.C. circuit without (almost) consuming any power.

The choke coil is extensively used in tube lights–an essential device for home and office lighting.

Alternating Currents

An alternating electric current is one which passes through a complete cycle of changes at regular intervals. In dealing with alternating currents calculations are usually made on the assumption that the voltage applied to the circuit is sinusoidal. But in practice there are many alternating currents which have wave forms other than a sine curve. But, however, peculiar in shape a wave form may be, it can always be analysed as the sum of a number of sine wave forms by Fourier's theorem.

Sinusoidal function can be constructed and displayed by plotting the projection of a component of a uniformly *rotating generating vector* against time.

Effective Value of an A.C. Quantity

An alternating current is said to have an *effective value* of I ampere when it develops the same amount of heat in a given resistance as would be produced by a direct current of I ampere in the same resistance in the same time.

Thus, $I = \frac{I_M}{\sqrt{2}}$, where I_M is the peak value of the current. The effective values of the current and voltage are also called the "*root mean square*" values.

Effect of an externally applied Alternating e.m.f. on a Resistor, Inductor and a Capacitor

When an a.c. is applied to a pure resistance, inductance or capacitance in general there is a phase difference between the applied e.m.f. and the current flowing in the element. Also, we can associate a impedance with the considered element.

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It can be shown that

$Z_R = R$	resistive impedance	I in phase with V
$Z_L = \omega L = X_L$	inductive reactance	I lags V by 90°
$Z_o = \frac{1}{\omega C} = X_o$	capacitative reactance	I leads V by 90°

A.C. applied to a Series LR Circuit

In a series L–R circuit, the sinusoidal current is given by

$$I = \frac{E_M}{Z} \sin(\omega t - \alpha), \text{ where } Z = \sqrt{R^2 + L^2\omega^2}$$

and α, the angle by which the current lags the voltage is given by $\tan \alpha = \frac{L\omega}{R}$

A.C. applied to a Series CR Circuit

In a series C-R circuit

$$I = \frac{E_M}{Z} \sin(\omega t + \alpha), \quad \text{where } Z = \sqrt{R^2 + \frac{1}{\omega^2 C^2}}$$

In series C–R circuit the current leads the applied e.m.f. by an angle α.

A.C. applied to a Series LCR Circuit

In a series L–C–R circuit

$$I = \frac{E_M}{Z} \sin(\omega t - \alpha), \text{ where } Z = \sqrt{R^2 + \left(L\omega - \frac{1}{\omega C}\right)^2} \text{ and } \tan \alpha = \frac{(L\omega - 1/\omega C)}{R}$$

Thus, if α is positive the applied e.m.f. lags the current, whereas, if α is negative, the current leads the applied e.m.f.

Resonance in a Series LCR Circuit

Since the impedance of an a.c. circuit is a function of frequency, the current through an L-C-R circuit varies with frequency. In a series L-C-R circuit a *maximum* current occurs when the two reactance terms are of equal size, given by the condition

$$\omega = \frac{1}{\sqrt{LC}}, \text{ where}$$

ω is called the *resonance frequency* of the circuit. The smaller the resistive term R compared with either of the reactive terms at resonance the more rapidly the current varies with frequency around the resonance value or the sharper is the resonance peak. Another useful way of describing the sharpness of resonance of the series circuit is to specify the width of the resonance curve at a point at which the current is half the value at resonance.

Power Factor

The power dissipated in an a.c. circuit by passing an a.c. current of amplitude I_M and having across it an a.c. voltage of amplitude E_M depends on the phase difference between current and voltage. Accordingly $P = I_e V_e \cos\phi$, $\cos\phi$ is called the power factor of the circuit.

The Phasor Diagrams

A diagram, showing the phase relationship between the current and voltage in an A.C. circuit, is known as a *phasor diagram.* We use phasor diagrams extensively for analysing A.C. series circuits.

Phasor Diagrams for pure Resistor, Inductor and Capacitor

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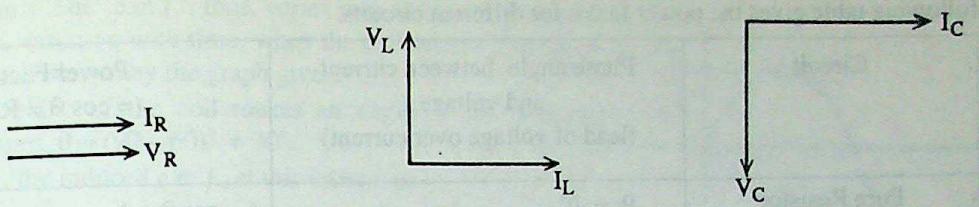
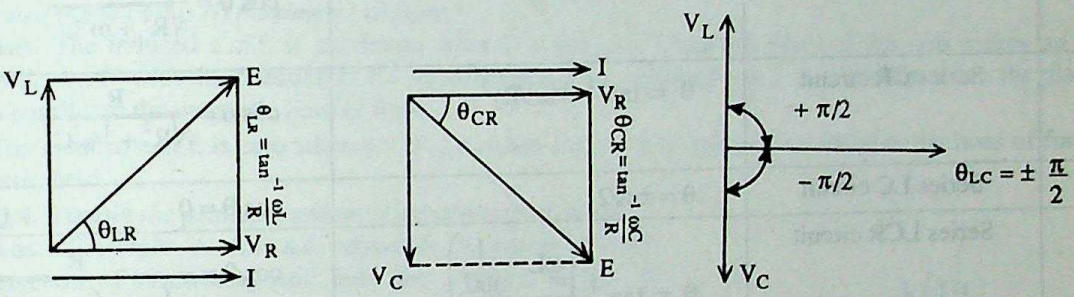
The phasor diagrams for a pure resistor, a pure inductor and a pure capacitor are as shown below :



(a) Pure resistor (b) Pure inductor (c) Pure capacitor

Phasor Diagrams for Series LR, CR and LC Circuits

The phasor diagrams for these cases are as shown below: In all cases, E represents the applied alternating e.m.f.

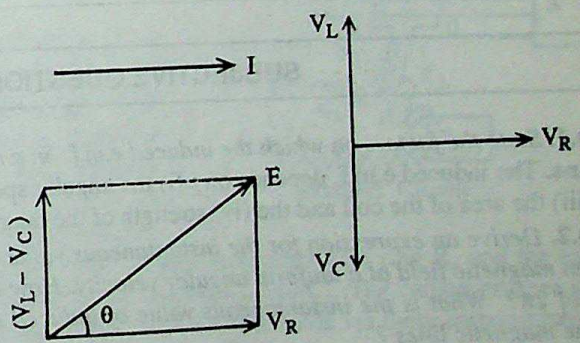


(a) LR circuit (b) CR circuit (c) LC circuit

Phasor Diagrams for Series LCR Circuit

The phasor diagram for a series LCR circuit is shown below. As before, E represents the applied alternating e.m.f.

$$\theta_{LCR} = \tan^{-1}\left(\frac{\omega L - \frac{1}{\omega C}}{R}\right)$$



Wattless Circuits

We notice from above, that for all circuits with zero resistance (pure L, pure C, pure LC), the power factor is *zero*. We call these circuits as wattless circuits. This is because the average power consumed by these circuits, over one full cycle, in zero.

Quality Factor

The quality factor of a series LCR circuit is defined by

$$Q = \frac{\omega_0 L}{R} = \frac{\frac{1}{\omega_0 C}}{R}, \text{ where } \omega_0 = \frac{1}{\sqrt{LC}}$$

Thus, $Q = \frac{\sqrt{L/C}}{R}$.

'Q' is a measure of the (i) voltage magnification obtainable from a series LCR circuit at its resonant frequency and (ii) the sharpness of resonance of the circuit.

We can increase Q by decreasing the resistance of the LCR circuit.

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Angle Phase and Power Factor for different Cases

The following table gives the power factor for different circuits.

S. No.	Circuit	Phase angle between current and voltage (lead of voltage over current)	Power Factor (= cos θ = R/Z)
1.	Pure Resistor	$\theta = 0°$	$\cos\theta = 1$
2.	Pure Inductor	$\theta = +\pi/2$	$\cos\theta = 0$
3.	Pure Capacitor	$\theta = -\pi/2$	$\cos\theta = 0$
4.	Series LR circuit	$\theta = \tan^{-1}(\omega L/R)$	$\cos\theta = \frac{R}{\sqrt{R^2 + \omega^2 L^2}}$
5.	Series CR circuit	$\theta = \tan^{-1}(1/\omega CR)$	$\cos\theta = \frac{R}{\sqrt{R^2 + 1/\omega^2 C^2}}$
6.	Series LC circuit	$\theta = \pm\pi/2$	$\cos\theta = 0$
7.	Series LCR circuit	$\theta = \tan^{-1}\left(\frac{\omega L - \frac{1}{\omega C}}{R}\right)$	$\cos\theta = \frac{R}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$

SUBJECTIVE QUESTIONS ON UNIT – VI B

Q.1. *State the factors on which the induced e.m.f. in a coil rotating in a uniform magnetic field depends.*

Ans. The induced e.m.f. depends on : (i) the angular speed of the rotating coil (ii) the number of turns in the coil, (iii) the area of the coil and the (iv) strength of the magnetic field in which the coil is rotating.

Q.2. *Derive an expression for the instantaneous value of the induced e.m.f. in a coil when it is rotated in a uniform magnetic field at a uniform angular velocity. How does the e.m.f. vary when the coil rotator through an angle of 2π? What is the instantaneous value of induced e.m.f. when the plane of the coil makes angle of 0° with the magnetic lines ?* **(C.B.S.E 1995 Comptt)**

Ans. Let us consider the coil at an instant 't' when its area vector is making an angle θ with the direction of the magnetic field. If A is the area of each turn of the coil and n is the number of turns in it, the total flux linked with it, at this instant, is

$\phi = n A B \cos\theta$

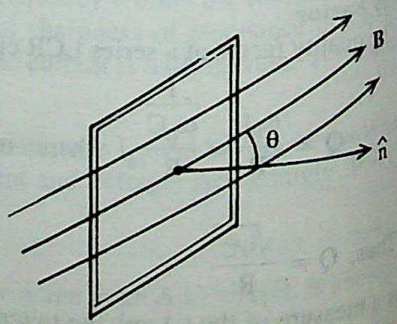
Hence, the induced e.m.f., at this instant, is

$$e = -\frac{d\phi}{dt} = +nAB \sin\theta \frac{d\theta}{dt}$$

If ω is the angular speed of the rotation of the coil, we have

$$\omega = \frac{d\theta}{dt} \text{ and } \theta = \omega t$$

Hence, $e = nAB\,\omega \sin(\omega t) = e_o \sin\omega t$, where $e_o = nAB\,\omega$.



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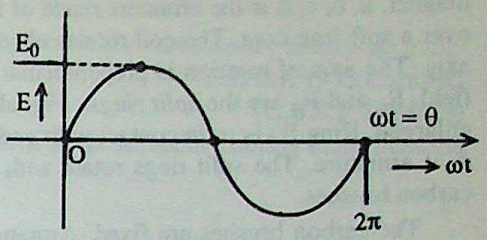
This is the expression for the instantaneous value of the induced e.m.f. The 'e.m.f.', thus, varies with time in a sinusoidal way and its variation with time, when the coil rotates through an angle of 2π, is shown by the graph given.



When plane of the coil makes an angle of 60° with the magnetic lines, $\theta = (90 - 60)^\circ = 30^\circ$.

Hence, the induced e.m.f., at this instant, is

$$e = nAB\,\omega \sin 30^\circ = \frac{1}{2} nAB\,\omega = \frac{1}{2} e_0.$$

The induced e.m.f. at this instant is, therefore, 50% of its maximum value.

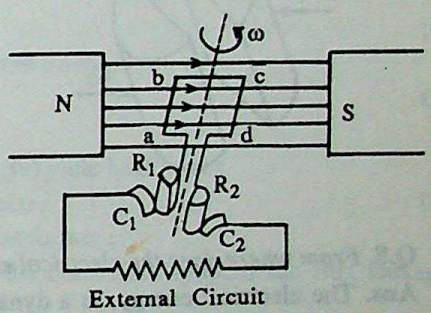
Q.3. *What should be the direction of the plane of coil with respect to the field direction so that e.m.f. generated in the coil is (i) maximum? (ii) zero?* **(1)**

Ans. The induced e.m.f. is maximum when $\theta = 90^\circ$, *i.e.*, when the plane of the coil makes an angle of $(90–90)^\circ$, *i.e.*, 0° with the direction of the lines of force. Thus, induced e.m.f. is maximum when the plane of the coil is parallel to the magnetic lines of force.

The induced e.m.f. is zero when $\theta = 0^\circ$, *i.e.*, when the plane of the coil is *normal* to the lines of force of the magnetic field.

Q.4. *Explain the principle and working of an a.c. dynamo.* **(2)**

Ans. *Principle :* An a.c. dynamo is based on the phenomenon of electromagnetic induction. A coil, known as armature is rotated with a uniform angular speed ω in a constant magnetic field B. A dynamo converts mechanical energy into electrical energy.



Construction : Fig alongside shows the construction of an a.c. generator. N, S are the pole pieces of a strong permanent magnet. N, S is the *field magnet, a b c d* is a rectangular coil of insulated copper wire and is known as the armature. It is wound over a soft-iron core. The armature is rotated with a uniform angular speed ω about the dotted lines as axis. The axis of rotation is perpendicular to the direction of the magnetic field. R_1 and R_2 are two *slip rings* made of brass. The end *a* of coil is always in contact with ring R_1 and the end *d* is in contact with ring R_2. The slip rings are in contact with carbon brushes C_1 and C_2. The carbon brushes are fixed, whereas the slip rings rotate with armature. The cantact to external circuit is made via these carbon brushes.

The instantaneous induced e.m.f. $e = e_0 \sin \omega t$, If R is the resistance of external circuit the instantaneous current I is $I = e/R$ or $I = I_0 \sin \omega t$, where $I_0 = e_0/R$. The current in external circuit is an *alternating current.*

Q.5. *Explain, with the help of a labelled diagram, the principle, construction and working of an a.c. generator.* **(C.B.S.E 1994, 1998)**

Ans. Refer to answer no. (4) above.

Q.6. With the help of a labelled diagram explain the construction and working of an a.c generator. **(C.B.S.E 1995) (5)**

Ans. Refer to answer no. 4 above.

Q.7. *If a coil is rotated in a magnetic field, discuss the nature of the e.m.f. produced. Explain, how this phenomenon is used in the construction of an a.c. dynamo. Show how it can be converted into a d.c. dynamo.* **(3)**

Ans. Refer to answer no. 2 and answer no. 4 above

To convert an a.c dynamo into a d.c. dynamo, we use a *split ring commutator* instead of the slip rings used in the a.c. dynamo. We give below the essential details of the d.c. dynamo.

The principle of a d.c. generator is same as that of an a.c. generator. However, the a.c. produced in armature is converted into a *uni-directional e.m.f.* by using *split rings.*

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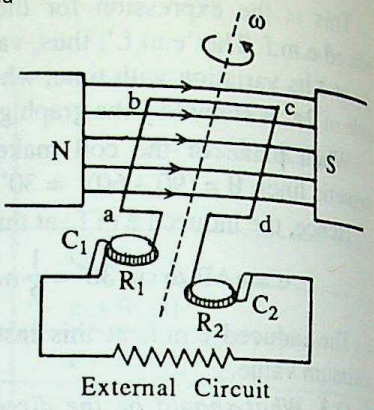
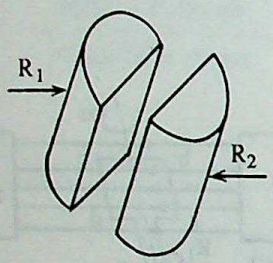
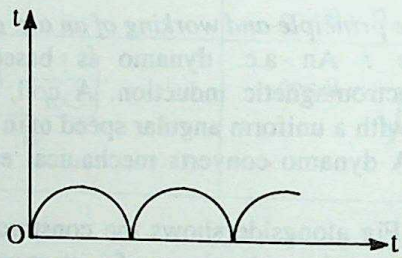
Construction : N, S are the pole pieces of a strong permanent field magnet. a, b, c, d is the armature made of insulated copper wire, wound over a soft-iron core. The coil rotates about dotted line shown in fig. as axis. The axis of rotation is prependicular to the direction of magnetic field. R_1 and R_2 are the *split rings.* Fig. alongside shows the split rings enlarged. Ring R_1 is in in contact with end *a* and R_2 is contact with end *d* of armature. The split rings rotate with the armature. C_1 and C_2 are carbon brushes.



The carbon brushes are fixed. Armature is so arranged that during one half of cycle of rotation R_1 is in contact with C_1 and R_2 in contact with C_2. However, during the second-half cycle of rotation R_2 comes in contact with C_1 and vice-versa. If end a was +ve during the first half of one cycle of rotation, C_1 is +ve. During second half, d become +ve and a becomes -ve. However, now d is in contact with C_1 via split ring. The carbon brush C_1 is, therefore, always at +ve potential and C_2 is always at a -ve potential. The current in external circuit is in same direction throught the cycle of rotation. In other words, current in armature is a.c. but current in external circuit is unidirectional.





Q.8. *From where does the electrical energy come in a generator ?* (1)

Ans. The electrical energy, in a dynamo, comes from the *mechanical work* done in rotating the coil, The energy for this mechanical work, may, in turn, come from (i) chemical, (ii) thermal (iii) hydroelectric *or* (iv) nuclear sources.

Q.9. *Although direction of current through armature reverses after each half cycle yet it keeps on rotating in one direction. Why ?* (2)

Ans. In a generator, the armature is rotated by an external (mechanical) agency which always rotates it in one sense only. The current, reversing after each half cycle, is produced as a result of this unidirectional (by external means) rotation of the coil.

In a motor, the sense of the current through the armature and the sense of the magnetic field both get reversed after every half cycle. Hence, the torque on the armature keeps on acting in the same sense and it, therefore, keeps on rotating in one sense only.

Q.10. *What is a transformer ?* (2)

Ans. A transformer is a device that can be used to step-up or step-down the voltage of an a.c. source.

Q.11. *Explain the principle of the working of a transformer.* (2)

Ans. The transformer works on the principle of electromagnetic induction. Here the magnetic flux linked with a secondary coil is made to change continuously because of the passage of an (continuously changing) a.c. current through primary coil. Because the magnetic flux linked with the secondary is (continuously) changing, there is a continuous (and changing) (a.c.) e.m.f. induced in it.

Q.12. *Can a transformer be used to alter d.c.voltages?* (1)

Ans. No, the transformer cannot be used to alter a d.c. voltage.

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(With a d.c. source, the magnetic flux linked with the secondary remains at a steady constant (non changing) value and hence there is no induced e.m.f. in it)

Q.13. *(a) What device will you use to step up an a.c voltage ? Can we use the same device to step up a d.c. voltage ?* **(C.B.S.E 1993 Comptt)**

(b) Why can't a transformer be used to step up a d.c. voltage ? **(C.B.S.E 1993) (3)**

Ans. (a) We use a step-up transformer in which the number of turns in its secondary coil is more than the number of turns in its primary coil to step up an a.c. voltage.

We cannot use a transformer to step up a d.c. voltage.

(b) The transformer works on the principle of electromagnetic induction. In a d.c. voltage, there is no change in the flux linked with the primary, and hence, there cannot be any induced e.m.f. in the secondary.

Q.14. *Is the number of turns in secondary more or less than the number of turns in primary if the transformer is a (a) step down transformer (b) step-up transformer ?* **(1)**

Ans. (a) For a step down transformer, the number of turns in the secondary is *less* than the number of turns in its primary.

(b) For a step-up transformer, the number of turns in the secondary is *more* than the number of turns in its primary.

Q.15. *Why is the core of a transformer made of magnetic material of high permeability ?* **(1)**

Ans. We use a core of magnetic material of high permeability to reduce the flux leakage losses to a minimum. We want all the magnetic lines of force to pass through the core and this is possible only if the core is made of a material of high magnetic permeability.

Q.16. *Why is the core of transformer laminated ?* **(1)**

Ans. The core of a transformer is laminated to reduce the eddy current losses in it.

Q.17. *Name the energy losses in a transformer.* **(1)**

Ans. The main causes of energy loss in a transformer are :

(i) flux leakage losses (ii) hysteresis losses (iii) eddy current losses (iv) joule heat losses.

Q.18. *How can the various energy losses in a transformer be minimised ?* **(2)**

Ans. We use the following steps to reduce the energy losses in a transformer :

(i) Use of a material of high magnetic permeability for making the core. This reduces the flux leakage losses.

(ii) Use of a soft ferromagnetic material (with as narrow a hysteresis curve as possible) to reduce the hysteresis losses.

(iii) Use of a laminated core to reduce the eddy current losses.

(iv) Use of a relatively thick copper wire for winding the coils. This reduces the joule heat losses.

Q.19. *In a step-up transformer, a high voltage is obtained by supplying a low a.c. voltage. Does it not contradict the principle of conservation of energy ?* **(2)**

Ans. No; there is no contradiction of the energy conservation principle. The rate of energy production/consumption in an electrical device is the product of its voltage and the current through it.

In a transformer, the stepping up of the voltage in its secondary is accompanied by a stepping down of the current in it. The product, voltage × current, therefore, remains at the same value (or, in practice is a little less, because of energy losses) as its value in the primary. This is in accord with the law of conservation of energy.

Q.20. *In an ideal transformer what is the ratio of the input and output power ?* **(1)**

Ans. The ratio of the output power to the input power, in an *ideal transformer* (in which there are no energy losses whatsoever) is *one* [It is always (a little) less than one in an actual transformer.]

Q.21. *In an actual transformer the output power is always less than the input power. Why ?* **(2)**

Ans. There are always some energy losses in an actual transformer. [Refer to answer to question no. 17 for the names of the various causes of energy losses]. Hence, the output power obtained is always less than the input power.

Q.22. *Why is a humming sound produced when a transformer is placed on a sheet of iron ?* **(2)**

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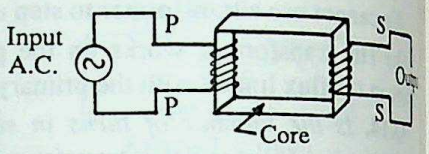
Ans. The iron sheet keeps on getting magnetised and demagnetized alternately and, therefore, keeps getting attracted and released. Its vibrations, therefore, produce a humming sound.

Q.23. *Explain, with the help of a diagram, the principle, construction and working of a step-up transformer. Why is the core laminated ?* **(C.B.S.E 1995)**

Ans. For cause of lamination of the core, refer to answer to question no. 16 above.

Principle : A transformer is based on the principle of mutual induction.

Construction : A transformer basically consists of a soft-iron core as shown in fig alongside. A finite number of turns of insulated copper wire are wound on the two limbs of the core. One of these windings known as the primary P,P has input a.c. connected to it. The other windings is known as the secondary SS. The output voltage is obtained across the secondary.



Working : Let V_p and V_S indicate the input and output voltage respectively. The number of turns in primary and secondary is N_p and N_S respectively. Let $\frac{d\phi}{dt}$ be the rate of change of flux per turn of the primary PP. The induced e.m.f. per turn of PP is $-\frac{d\phi}{dt}$. The total induced e.m.f. in PP is $-N_p \frac{d\phi}{dt}$. According to Faraday's law, $V_p = -N_p \frac{d\phi}{dt}$ ...(i)

Assuming that there is no leakage of magnetic flux (i.e., the entire magnetic flux due to current in primary is linked with secondary), the rate of change of magnetic flux per turn of secondary is also $\frac{d\phi}{dt}$. The output voltage V_s, is the total induced e.m.f. in SS due to varying flux of PP. From Faraday's law,

$$V_s = -N_s \frac{d\phi}{dt} \quad \text{...(ii)}$$

From Eqns (i) and (ii) $\frac{V_s}{V_p} = \frac{N_s}{N_p}$ ...(iii)

If $V_s > V_p$; $N_s > N_p$, and we have a *step-up* transformer. On the other hand, if $V_s < V_p$ or $N_s < N_p$, we have a *step-down* transformer. The ratio N_s/N_p is known as the transformer ratio.

In an *ideal-transformer* the output voltage may be more or less than input voltage depending upon whether it is step-up or step-down transformer. There is no loss or generation of power. Let I_p and I_s denote the primary and secondary current. The input power.

$P_I = V_p \cdot I_p$. The output power $P_O = V_s \cdot I_s$. For an ideal transformer $P_I = P_O$ or $V_p I_p = V_s I_s$ ...(iv)

$\therefore \quad V_s/V_p = I_p/I_s$

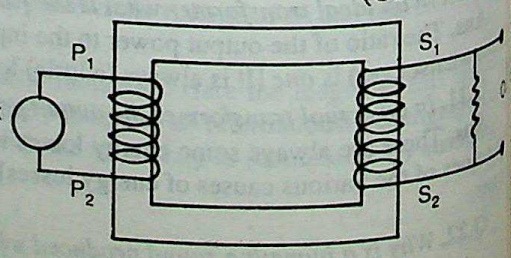
From Eqns (iii) and (iv)

$$V_s/V_p = I_p/I_s = N_s/N_p \quad \text{...(v)}$$

If $V_s > V_p$; $I_s < I_p$ and vice-versa. In any actual transformer there is always some loss of energy, i.e., $P_o < P_i$. The efficiency η of a transformer is η = (output power/input power) × 100%.

Q.24. *Draw a labelled diagram of a step-down transformer. Mention two source of energy losses in a transformer.* **(CBSE 1999) (1**

Ans. In a step down transformer, secondary coil consists of only a few turns of thick insulated copper wire, while the primary coil consists of a vary large number of turns of fine insulated copper wire. Energy losses in a transformer are: (i) copper loss (ii) flux loss.



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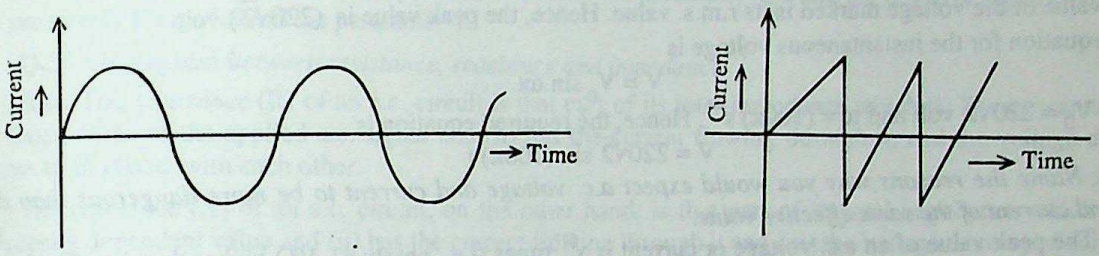
Q.25. *Explain with the help of a labelled diagram, the principle, construction and working of a transformer.* **(CBSE 1998) (5)**

Ans. See answer to question 11 and 23.

Q.26. *What do you mean by an alternating current ? How does an alternating current differ from a direct current ?* **(2)**

Ans. An alternating current is a current that keeps on changing, in magnitude as well as direction, in a regular periodic manner. A direct current is a current that remains fixed in magnitude as well as indirection. Flow of direct current in similar toflow of water through a pipe. The following current versus time graphs indicate two possible types of alternating currents.



Q.27. *Explain, why in dealing with alternating current parameters we use only sinusoidal functions.* **(2)**

Ans. We need talk only of sinusoidal parameters, because, as per *Fourier's theorem,* any periodic function, whatsoever, can be expressed as the sum of a series of sinusoidal functions, Thus, any general type of alternating current can be viewed as 'made up' from sinusoidal currents. We, therefore, need talk of sinusoidal parameters only.

Q.28. *What is the average value of a.c. over one full cycle ?* **(1)**

Ans. The (simple) average of an a.c., over one full cycle, is zero.

Q.29. *What is the average value of a.c. over half cycle ?* **(1)**

Ans. The (simple) average value of an a.c. over half the cycle is $\frac{2}{\pi}$ times its peak value.

Q.30. *Explain the meaning of the term root mean square current.*

Ans. Suppose we take the sum of the squares of the instantaneous currents and then calculate the average (or mean) value of this square of the current. If we then calculate the square root of this mean square value, we call the result as the root mean square value (**or** r.m.s value) of the current. Thus, for one cycle of an a.c., the r.m.s value would be defined by

$$I_{r.m.s.} = \left[\frac{1}{T}\int_0^T I^2(t)\,dt\right]^{1/2}$$

Q.31. *(a) What is meant by the root mean square or effective value of alternating current ? Derive a relation between it and its peak value. (b) The electric mains in the house are marked 220 V, 50 Hz. Write down the equation for instantaneous voltage.* **(C.B.S.E 1995 Comptt) (5)**

Ans. For definition of the r.m.s. value, refer to answer no. 30 above.

The relation between the r.m.s. value and the peak value can be derived as follows :

Let the given a.c. current be represented by $I = I_0 \sin \omega t$.

We then have, by definition,

$$I^2_{r.m.s.} = \frac{1}{T}\int_0^T I_0^2 \sin^2 \omega t\, dt = \frac{I_0^2}{T}\int_0^T \left(\frac{1-\cos 2\omega t}{2}\right) dt$$

$$= \frac{I_0^2}{T}\left[\int_0^T \frac{1}{2}\,dt - \int_0^T \frac{\cos 2\omega t\, dt}{2}\right] = \frac{I_0^2}{T}\left[\left|\frac{t}{2}\right|_0^T - \left|\frac{\sin 2\omega t}{4\omega}\right|_0^T\right]$$

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$$= \frac{I_0^2}{T}\left[\frac{T}{2} - \frac{1}{4\omega}(\sin 2\pi - \sin 0)\right] = \frac{I_0^2}{T}\left[\frac{T}{2} - \frac{1}{4\omega}(0-0)\right] = \frac{I_0^2}{2}$$

$$\therefore\ I_{r.m.s.} = \frac{I_0}{\sqrt{2}}$$

Thus, the r.m.s. value is $\frac{1}{\sqrt{2}}$ times the peak value of the current.

(b) We are given that the frequency is 50 Hz. Hence, $\omega = 2\pi\nu = 2\pi \times 50\ s^{-1} = (100\,\pi)\ s^{-1}$
The value of the voltage marked is its r.m.s. value. Hence, the peak value is $(220\sqrt{2})$ volt.
The equation for the instantaneous voltage is

$$V = V_0 \sin \omega t$$

Here $V_0 = 220\sqrt{2}$ volt and $\omega = (100\pi)\ s^{-1}$. Hence, the required equation is

$$V = 220\sqrt{2} \sin (100\pi)\, t$$

Q.32. *Name the reasons why you would expect a.c. voltage and current to be more dangerous than d.c. voltage and current of the same effective value.* (1

Ans. The peak value of an a.c. voltage or current is $\sqrt{2}$ times (i.e., nearly 41.4%) higher than its effective or *r.m.s.* value. Further, the a.c. voltage or current would attain this value 2ν times (2ν = frequency of a.c.) in one second. It is this that makes a.c. voltages and currents potentially more dangerous than d.c. voltages or currents.

For example, for the usual household mains, (effective voltage value = 220 V, frequency = 50 Hz), an a.c. voltage would be at a magnitude of (nearly) 310 V.as much as 100 times in one second.

Q.33. *What is the relation between r.m.s and peak value of current or voltage in an a.c. ?* (1

Ans. The r.m.s. value of an a.c. voltage/ current is $\frac{1}{\sqrt{2}}$ times its peak value. Thus,

$$I_{r.m.s.} = \frac{I_{max}}{\sqrt{2}} \text{ and } V_{r.m.s.} = \frac{V_{max}}{\sqrt{2}}$$

Equivalently, $I_{max} = \sqrt{2}\ I_{r.m.s.}$ and $V_{max} = \sqrt{2}\ V_{r.m.s.}$

Q.34. *Distinguish between the 'mean value' ''peak value' and ''r.m.s value'' of an alternating current and find the relation between them.*

Ans. The *mean value* of an alternating current is defined as the magnitude of the average of its values over *half* the cycle.

Thus,
$$I_{mean} = \frac{1}{\pi}\int_0^{\pi} I_0 \sin \omega t\, d(\omega t) = \frac{\omega}{\pi}\int_0^{\pi} I_0 \sin \omega t\, dt$$

$$= \frac{\omega}{\pi} I_0 \left|\frac{-\cos \omega t}{\omega}\right|_0^{\pi} = \frac{-I_0}{\pi} |\cos \pi - \cos 0|$$

$$= -\frac{I_0}{\pi}[-1 - 1] = \frac{2I_0}{\pi}$$

The mean value is, thus, $\frac{2}{\pi}$ times the peak value. For definition of the *r.m.s.* value and for derivation of its relation with the peak value, refer to answers to question no 30 and 31 above. We get $I_{r.m.s.} = \frac{I_0}{\sqrt{2}}$

The *peak value* of an a.c. is, of course, the magnitude of the maximum value attained by it over one full cycle. We, thus, have

$\frac{\pi}{2}(I_{mean}) = \sqrt{2}\ (I_{r.m.s.}) = I_0$, where I_0 = the peak value of the a.c.

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Q.35. *Two alternating parameters X and Y have a phase difference θ. Explain what do you understand by this statement.* **(2)**

Ans. When there is a phase difference θ (= ωt) between the two parameters X and Y, these parameters would not be attaining their maximum or minimum or any other given value at the same time. If any such value is attained by the parameter X at a time t_1, the same value would be attained by the parameter Y at a time t_2, where

$$t_2 = \left(t_1 \pm \frac{\theta}{\omega}\right)$$

The plus sign is to be used if the parameter X leads the parameter Y while the negative sign is to be used if the parameter X lags behind the parameter Y.

Q.36. *Distinguish between resistance, reactance and impedance.* **(2)**

Ans. The *resistance* (R) of an a.c. circuit is that part of its total impedance which (i) has the same value at *all* frequencies of the applied a.c. signal and (ii) has the current flowing through it, and the voltage developed across it, in phase with each other.

The reactance (X) of an a.c. circuit, on the other hand, is that part of its total impedance which (i) has a frequency dependent value and (ii) has the current flowing through it and (iii) the voltage developed across it not in phase with each other.

The impedance (Z) of an a.c. circuit is an indicator of the total opposition provided by it to the flow of an a.c. current through it. It is the resultant of the resistance and the reactance of the circuit and is obtained from the two through the relation

$$Z = \sqrt{R^2 + X^2}$$

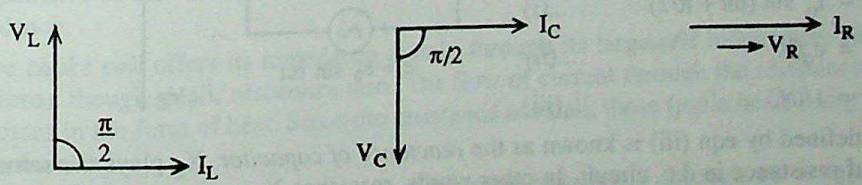
Q.37. *Distinguish between the terms reactance and impedance of an a.c. circuit.* **(C.B.S.E. 1994)**

Ans. The opposition to the flow of current in an a.c. circuit is provided by devices like the resistors, inductors and capacitors. Of these the inductors and the capacitors differ from the resistors in two important respects :

(a) The impedance (X_L) of an inductor and (X_C) of a capacitor are *dependent on the frequency of the applied a.c.* The impedance X_R of a resistor is, however, frequency independent. In fact.

$$X_L = \omega L,\ X_C = \frac{1}{\omega C},\ X_R = R$$

(b) The voltage drops across an inductor (X_L) and across a capacitor (V_C) are *not in phase* with the current through them. For a resistor, the voltage drop (V_R) is in phase with the current through it. We may represent these facts by the following phase diagrams.



We call the inductor and the capacitor as reactive impedances while the resistor is referred to as simply a resistive impedance.

The resultant frequency dependent parts of the impedance of an a.c. circuit, due to the inductors and capcitors in it, is referred to as its reactance. The impedance of a given a.c. circuit is the resultant of all the reactive and resistive impedances present in it.

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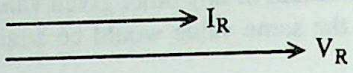
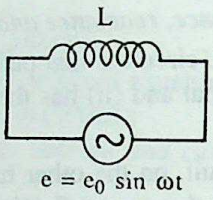
Q.38. *What is the phase relation between current and p.d in a pure resistance a.c. circuit ?*

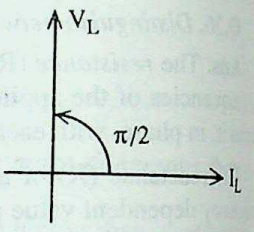
Ans. The current and the p.d., in a pure resistance, have a zero phase difference in a.c. circuit. In other words, the current through the reactor, and the p.d. across it, are in phase with each other.



Q.39. *A sinusoidal e.m.f. is applied to a circuit containing an inductor only. Show that current lags behind the voltage by π/2.* **(C.B.S.E. 1995 Comptt.)**

Ans. Fig. below shows a *pure inductance* (L) connected to an a.c, $e = e_0 \sin \omega t$. Let I be the instantaneous current in circuit. Since current in circuit is changing there is an induced e.m.f $= -L\frac{dI}{dt}$ across inductance. According to Kirchoff's law





$$e + \left(-L\frac{dI}{dt}\right) = 0$$

or $$e_o \sin \omega t = L\frac{dI}{dt}$$

$$\therefore \quad \frac{dI}{dt} = \frac{e_o}{L}(\sin \omega t) \qquad ...(i)$$

$$I = -(e_o/\omega L)\cos \omega t = I_o \sin(\omega t - \pi/2) \qquad ...(ii)$$

where $$I_o = e_o/\omega L = e_o/X_L \text{ and } X_L = \omega L \qquad ...(iii)$$

Quantity X_L defined by eqn (iii) is known as *reactance of inductance.* It plays the same role in a.c. circuit as is the role of resistance in d.c. circuit. We can also say that reactance is a measure of the opposition offered by inductance to the flow of a.c. current. Comparing the expression for e and i we note that current and applied p.d are not in same phase. The current lags *behind the applied voltage by* π/2.

Q.40. *A sinusoidal e.m.f. is applied to a circuit containing capacitor only. Show that current leads the voltage by π/2.* **(C.B.S.E 1995 Comptt.)**

Ans. Fig. below shows a *pure capacitor* C connected across an a.c. represented by $e = e_0 \sin \omega t$. Let q and i denote the instantaneous charge and instantaneous current in the circuit.

By definition $q = Ce = C e_0 \sin \omega t$. The instantaneous current,

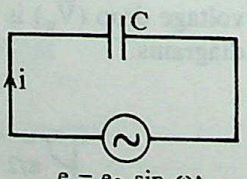
$$I = \frac{dq}{dt} = C e_0 \omega \cos \omega t$$

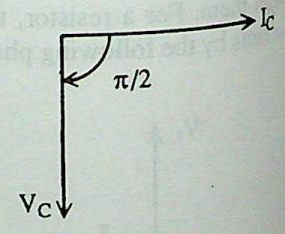
$$= [e_0/(1/\omega C)] \cos \omega t$$

$$= I_0 \sin(\omega t + \pi/2) \qquad ...(i)$$

where $$I_0 = e_0/X_c \qquad ...(ii)$$

and $$X_c = 1/\omega C \qquad ...(iii)$$





The quantity X_c defined by eqn (iii) is known as the *reactance of capacitor.* X_C plays the same role in a.c. circuit as is the role of resistance in d.c. circuit. In other words, reactance X_c is a measure of the opposition the capacitor offers to the flow of a.c. Comparing expression for e and I we note the current and applied a.c. are not in phase. In capacitor, the current leads the applied voltage by π/2.

Q.41. *What is reactance of an inductance ?*

Ans. The reactance of an inductance (X_L) is the product of the angular frequency (ω) of the applied alternating e.m.f. and the self inductance (L) of the inductance. Thus,

$$X_L = \omega L = (2\pi\nu L)$$

Here ν = frequency of the applied alternating e.m.f.

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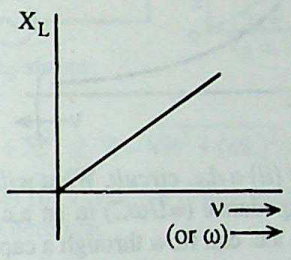
Q.42. *Give an expression for reactance of an inductance.* **(1)**

Ans. We have $X_L = \omega L = 2\pi \nu L$,

where the symbols have the meaning explained in answer to question no. 41.

Q.43. *Show graphically the variation of inductive reactance with frequency.* **(1)**

Ans. The inductive reactance varies with the frequency (of the applied alternating e.m.f.) in a linear way. This is shown in fig. below.



Q.44. *What is the reactance of an inductor in a d.c. circuit ?* **(1)**

Ans. The reactance of an inductor (pure inductor) in a d.c. circuit is zero.

Q.45. *What is the average power consumed in a purely inductive a.c. circuit ?* **(1)**

Ans. The average power consumed in a purely inductive circuit, over one cycle, is *zero.*

Q.46. *What is a wattless current ?* **(1)**

Ans. A *wattless current* is one in which the average power consumed (from the source of alternating e.m.f.), over one full cycle, is zero.

Q.47. *Is current in a pure inductance connected across an a.c. source wattless ?* **(1)**

Ans. Yes; the current flowing in a pure inductive circuit, connected to a source of alternating e.m.f., is *wattless.*

Q.48. *What is the power factor of a purely inductive a.c. circuit ?* **(1)**

Ans. The power factor of a purely inductive circuit is zero.

Q.49. *What is a choke coil ? Discuss energy losses in the choke coil and compare these with the corresponding losses in a rheostat.* **(3)**

Ans. A *choke coil* is essentially a coil, of low resistance, wound on a ferromagnetic core. The use of a large number of turns, and the presence of the ferromagnetic core, makes its self inductance quite large but keeps its resistance at a low value. It is thus, a series LR circuit whose inductive impedance. (= ωL) is quite large in comparison to its resistive impedance (= R)

The impedance of the inductor as we know, is a wattless impedance. There are, therefore no energy losses in this impedance.

Now the *choke coil* offers its impedance mainly through its large self inductance. However, its coil has a finite (non-zero), though small, *resistance* also. The flow of current through the resistance will be accompanied by energy losses in the form of heat. Since the resistance is small, these (joule heat) energy losses are also quite small in a choke coil.

A *rheostat* on the other hand, offers its impedance completely through its resistance only. There are, therefore, relatively much larger (joule heat) energy losses in a rheostat.

Q.50. *What is capacitative reactance ?* **(1)**

Ans. The impedance, offered by a pure capacitor, to an alternating e.m.f. source, is known as a *capacitative reactance.* The capacitative reactance (X_c) of a capacitor, of capacity C, is given by

$$X_c = \frac{1}{(\omega C)} = \frac{1}{(2\pi \nu C)},$$

where ω = angular frequency and ν = frequency of the applied alternating e.m.f.

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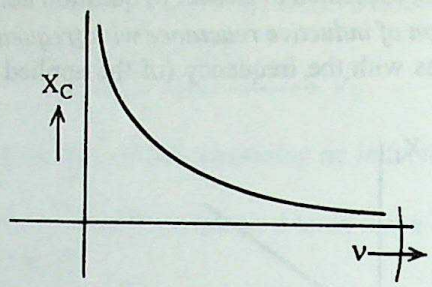
Q.51. *Show graphically the variation of capacitative reactance with frequency.*

Ans. The capacitance reactance X_c is inversely proportional to the frequency (ν) of the applied alternating e.m.f. This is shown graphically in fig. below.



Q.52. *A capacitor is used in (i) a.c. circuit (ii) a d.c. circuit. What will be the difference in its behaviour?*

Ans. The capacitor will act as a finite impedance (=1/ωC) in an a.c circuit. However, its impedance for a d.c. circuit would be *infinite*. Thus, whereas an a.c. can flow through a capacitor, a d.c. cannot flow through it.

Q.53. *Explain why does a capacitor act as a short circuit at high frequencies. Why does it act as an open circuit at low frequencies ?*

Ans. The capacitative impedance is given by $X_c = 1/\omega C$

$\therefore$ $X_c \to 0$ as $\omega \to \infty$

and $X_c \to \infty$ as $\omega \to 0$.

Thus, the capacitative impedance becomes negligible at high frequencies and very high at low frequencies. We express this by saying that the capacitance acts as a short circuit (i.e., ~ zero impedance) at high frequencies and as an open circuit (*i.e.*, ~ infinite impedance) at low frequencies.

Q.54. *What is meant by the term power factor ?* (1)

Ans. The average power consumed by an A.C. circuit in one cycle, equals the product of its effective voltage and effective current and an additional term $\cos\theta$

Thus, $P_{AV} = V_{r.m.s.} I_{r.m.s.} \cos\theta$

Here θ is the phase difference between the current and the voltage in the circuit.

The factor $\cos\theta$ is known as the *power factor* of the circuit. It is also equal to R/Z, where R is the resistance and Z is the total impedance of the circuit.

Q.55. *What is meant by the impedance of an a.c. circuit?* (1)

Ans. The impedance of an a.c circuit is the ratio of the effective value of the alternating e.m.f. (applied to it) to the effective value of the resulting alternating current flowing in it. Thus,

$$Z = V_{r.m.s.} / I_{r.m.s.}$$

Q.56. *Write an expression for the impedance of a series L-R circuit.* (1)

Ans. The impedance, Z, of a series L-R circuit is given by $Z = \sqrt{R^2 + \omega^2 L^2}$.

Q.57. *An a.c. circuit contains an inductor which has a resistance R. What is the power loss in the inductor?* (1)

Ans. The average power loss in the inductor is $I^2_{r.m.s.}$ R, where $I_{r.m.s.}$ is the effective current through the inductor.

Q.58. *A circuit contains an inductor and a resistance. If it is subjected to an alternating e.m.f. determine the current in the circuit. Also calculate the impedance and phase lag in the circuit.* (3)

Ans. Fig 20 shows a series L-R circuit with an external applied a.c. $e = e_0 \sin \omega t$. To calculate current in circuit we will use the phasor diagram or vector method. Let I be the instantaneous current in the circuit. The instantaneous voltage drop across resistance and inductance is $V_R = IR$ and $V_L = IX_L$ respectively. The current I and V_R are in *same phase*. This is shown in fig. (b) below. $OA = IR = V_R$. However V_L leads the current I by π/2. A lead is shown by an *anti clockwise* rotation in a phasor diagram. $OB = I X_L$ represents the magnitude and phase of V_L. The resultant OC is obtained by the vector addition of OA and OB . Let $OC = V = IZ$, where V is

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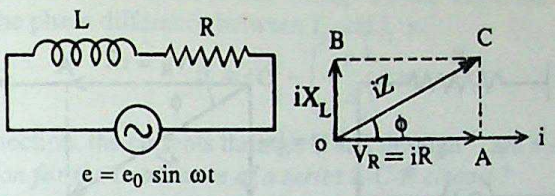
the resultant p.d. in L-R circuit. Z is known as impedance of circuit. It is obvious that impedance Z plays the same role as is of resistance in d.c. circuit.



$$Z^2 = R^2 + X_L^2 \text{ or } Z = \sqrt{R^2 + (\omega L)^2} \quad ...(i)$$

The impedance Z has (i) resistive and (ii) a reactive component. From fig (b) it is clear that the current I lags behind applied p.d. by a phase angle ϕ. Therefore,

$$I = I_o \sin(\omega t - \phi)$$

and

$$I_o = \frac{e_o}{Z} = \frac{e_o}{\sqrt{R^2 + \omega^2 L^2}} \quad ..(ii)$$

Thus, the impedance Z and the phase angle ϕ (lag of current behind voltage of a series LR circuit are given by

$$Z = \sqrt{R^2 + \omega^2 L^2} \text{ and } \phi = \tan^{-1}\left(\frac{\omega L}{R}\right)$$

Q.59. *Derive an expression for the impedance of an a.c.circuit with an inductor L and a resistance R in series.* **(C.B.S.E 1995)**

Ans. Refer to answer no. 58 above.

Q.60. *What is the impedance of a series C-R circuit ?* **(1)**

Ans. The impedance of a series CR circuit is given by $Z = \sqrt{R^2 + 1/\omega^2 C^2}$, where ω is the angular frequency of the applied alternating e.m.f..

Q.61. *A lamp is connected in series with a capacitor. Predict your observations for d.c and a.c connections. What happens in each case if the capacity is reduced ?* **(2)**

Ans. The impedance of a capacitor tends to infinity for a d.c. circuit. Hence, the current in such a circuit would be zero. This implies that the lamp would not glow when a d.c source is used irrespective of the value of the capacitance.

For the a.c., the impedance of the capacitor is $\frac{1}{\omega C}$. It is a finite impedance and its value increases as the capacity of the capacitor decreases. Thus, with an a.c. source, the lamp would glow. Further, the glow would become dimmer as the capacity is reduced.

Q.62. *An alternating e.m.f. is applied to the circuit having capacitance and resistance in series. Drive an expression for the nubedance and current in the circuit.*

Ans. Fig. (a) below shows a series C–R circuit connected to an a.c. $e = e_0 \sin \omega t$. Let I be the instantaneous current in the circuit and we calculate it using the *phasor diagram.* $V_R = IR$ is the instantaneous voltage drop across R and is in phase with current. This is shown in fig. (b) below The voltage drop $V_c = I X_c$ across capacitor lags behind current by π/2. A lag is shown by a clockwise rotation. In fig. (b) OB represents voltage drop across capacitor. The resultant of OA and OB is OC. Obviously, V = IZ, where Z is *impedance* of C-R circuit.

$Z^2 = R^2 + X_c^2$ or $Z = \sqrt{R^2 + (1/\omega c)^2}$. The resultant voltage drop lags behind current by phase angle ϕ, therefore,

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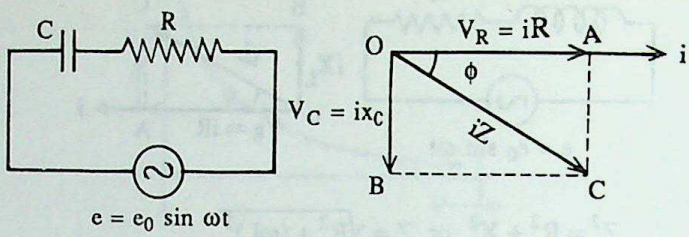
$I = I_0 \sin(\omega t + \phi)$

and $I_0 = e_o/Z = e_o / \sqrt{R^2 + (1/\omega c)^2}$



Note that impedance Z has (i) resistive part R and (ii) reactive part $X_c = \frac{1}{\omega C}$. Comparing expression for and e we note that current and applied e.m.f have a *phase difference* ϕ

Thus, the impedance Z and the phase angle ϕ of a series CR circuit are given by

$$Z = \left(R^2 + \frac{1}{\omega^2 C^2}\right)^{1/2} \text{ and } \phi = \tan^{-1} \frac{\left(\frac{1}{\omega C}\right)}{R}$$

Q.63. *In an L-C circuit the charge on the capacitor is sometimes zero, even though there is a current in the circuit. How is this possible ?*

Ans. The current in the circuit is the rate of flow of charge in it, *i.e.*, it is dq / dt, where q is the instantaneous charge in the circuit.

Now if a function (in this case, the instantaneous charge q) is zero at a particular instant, it is not necessary for its derivative (in this case, the instantaneous current, I = dq/dt) to be also zero at the same instant. We can therefore, have the current as non-zero even when the charge is zero.

Q.64. *An applied voltage signal consist of a superposition of a d.c voltage and an a.c voltage of high frequency. The circuit consist of an a.c inductor and a capacitor in series. Show that the d.c. signal will appear across C and the a.c. signal across L.*

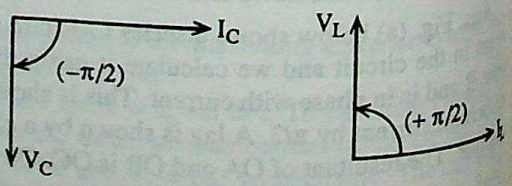
Ans. The impedances of a capacitor and an inductor are $1/\omega C$ and ωL respectively. Hence, the capacitor is an 'infinite' (very high) impedance for d.c., and a very low impedance for high frequancy a.c. The inductor, on the other hand, is a very low impedance for d.c. and a very high impedance for a high frequency a.c.

For a series circuit, the current is the same for all the elements and the voltage across each element is proportional to its impedance. It follows that the d.c. voltage will be very high across the capacitor and the a.c. voltage will be very high across the inductor. We express this by saying that the d.c. signal appears across the capacitor while the a.c signal appears across the inductor.

Q.65. *Explain-voltage across L and C in series are 180° out of phase, while for L and C in parallel currents in L and C are 180° out of phase.*

Ans. The current-voltage phase relationships for a capacitor and an inductor are as shown in fig.

For a *series* combination of L and C, the current through both is the same, *i.e.*, the currents through both are *in phase*. The voltage across L is $\pi/2$ ahead of this current in phase while the voltage accross C lags this current, in phase, by $\pi/2$. Hence, the phase difference between V_L and V_c is



$$\theta = \frac{\pi}{2} - \left(-\frac{\pi}{2}\right) = \pi$$

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Thus, for a series connection, the voltages across L and C are π out of phase with each other.

For a *parallel* connection of L and C, the voltages across both are the same, *i.e.*, the voltages across both are *in phase.* The current through C, however, *leads* this voltage by $\pi/2$ while the current through the inducor lags this voltage by $\pi/2$. Hence, the phase difference between I_c and I_L is

$$\theta' = +\frac{\pi}{2} - \left(-\frac{\pi}{2}\right) = \pi$$

Thus, for a parallel connection, the currents through C and through L are π out of phase with each other.

Q.66. *Write an expression for the impedance of a series L-C-R circuit ?* **(1)**

Ans. The impedance, Z, of a series LCR circuit when connected to an a.c. of frequency ν is given by $Z = \sqrt{R^2 + (\omega L - 1/\omega c)^2}$, where $\omega = 2\pi f =$ angular frequency of the applied a.c.

Q.67. *When is the impedance of a series L-C-R circuit a minimum ?* **(1)**

Ans. The impedance of a series LCR circuit is minimum at a frequency ν of the applied alternating e.m.f. for which

$$\omega L - \frac{1}{\omega C} = 0, \text{ (where } \omega = 2\pi\nu)$$

or $\omega^2 = \dfrac{1}{LC}$ or $\omega = \dfrac{1}{\sqrt{LC}}$ $\therefore$ $\nu = \dfrac{1}{2\pi\sqrt{LC}}$

This frequency of the applied alternating e.m.f. is known as the *resonant frequency* of the given LCR circuit.

Q.68. *What is the impedance of series L-C-R circuit at resonance ?* **(1)**

Ans. The impedance of a series LCR circuit is equal to R only at the resonant frequency $\left(\nu = \dfrac{1}{2\pi\sqrt{LC}}\right)$ of the circuit.

Q.69. *What is the phase difference between the current and the applied e.m.f. in a resonant L-C-R circuit?* **(1)**

Ans. The phase difference between the current and the applied alternating e.m.f., in a resonant LCR circuit, is *zero.*

Q.70. *Under what conditions is the power consumed in a series L-C-R circuit maximum ?* **(1)**

Ans. The power consumed in a series LCR circuit is maximum at its resonant frequency, *i.e.*, when the frequency of the alternating e.m.f. equals $\left(\dfrac{1}{2\pi\sqrt{LC}}\right)$.

Q.71. *At what frequency of applied a.c., is the current amplitude in a series L-C-R circuit maximum ?* **(1)**

Ans. The current amplitude in a series LCR circuit is maximum at the resonant frequency $\left(\nu = \dfrac{1}{2\pi\sqrt{LC}}\right)$ of the circuit.

Q.72. *The total impedance of a circuit decreases when a capacitor is added in series with L and R. Explain why.* **(2)**

Ans. The total impedance of a series LR circuit is $\sqrt{R^2 + \omega^2 L^2}$ and that of a series LCR circuit is $\sqrt{R^2 + (\omega L - 1/\omega C)^2}$. The second term, therefore, always *decreases* whenever a capacitor is added in series to a series LR circuit. The total impedance of the circuit, therefore, goes down on adding a series capacitor to a series LR circuit.

Q.73. *An alternating e.m.f e_o sin ωt is applied to the ends of a circuit containing a resistance R, a self inductance L and a capacitance C. Calculate the current at any instant. Deduce the condition under which electrical resonance occurs.* **(3)**

Ans. Fig. (a) below shows a L-C-R series circuit having an a.c. $e = e_0 \sin \omega t$ applied to it. Let I be the instantaneous current in circuit. To calculate I we use the phasor diagram shown in fig. (b). Here OA = V_R =

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IR, OB = $V_L = IX_L$ and OC = $V_c = IX_c$. The phase relation between current and voltage in L; C and R is shown in fig. (b). To obtain the resultant of OA; OB and OC, consider the following cases.

CASE I : $X_L > X_c$. The resultant of OB and OC is OD = I $(X_L - X_c)$ as shown in fig. (b). The complete resultant is OE as shown in fig. (c). Obviously, $OE^2 = OA^2 + OD^2$ or $Z^2 = R^2 + (X_L - X_c)^2$ or Z $\sqrt{R^2 + (\omega L - 1/\omega c)^2}$ the *impedance* of L-C-R circuit. It is also clear from fig. (c) that resultant voltage leads current by an angle ϕ. Therefore,

$$I = I_0 \sin(\omega t - \phi)$$

where $$I_o = \frac{e_0}{Z} = \frac{e_o}{\sqrt{R^2 + (\omega L - 1/\omega c)^2}}$$

CASE II : $X_L < X_c$. The resultant OE is obtained as shown in fig. (c). Again

$$Z^2 = R^2 + (X_c - X_L)^2$$

or $$Z = \sqrt{R^2 + (\omega L - 1/\omega c)^2}$$

However, now current leads resultant voltage by an angle ϕ; and $I = I_0 \sin(\omega t + \varphi)$

CASE III : $X_L = X_c$ The impedance Z = R, The current amplitude $I_0 = e_0$ /R. Let ω_r be the frequency of applied a.c., so that $X_L = X_c$. Obviously, $\omega_r L = \frac{1}{\omega_r C}$ or $\omega_r = \frac{1}{\sqrt{LC}}$, ω_r is known as the resonance frequency. At resonance the current and applied p.d. are in same phase. It is obvious that Z = R is the minimum value of impedance. Hence, current amplitude is maximum at resonance. Thus, for a series LCR circuit,

(i) The impedance is given by

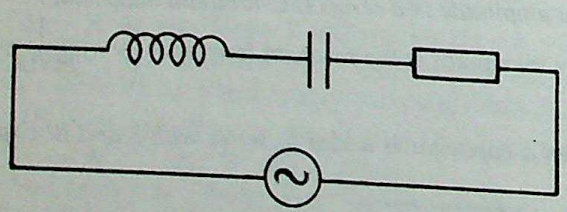
$$Z = \sqrt{R^2 + (\omega L - 1/\omega c)^2}$$

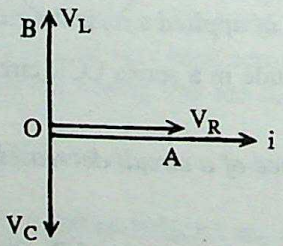
(ii) The 'phase lead' of the (applied) voltage over the (resulting) current is given by

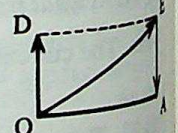
$$\phi = \tan^{-1}\left[\frac{\left(\omega L - \frac{1}{\omega c}\right)}{R}\right]$$

(iii) The circuit shows resonance at a frequency ν_R, where $\nu_R = \omega_r / 2\pi$ and

(iv) At the resonant frequency, the impedance of the circuit is R only and the phase difference between the (applied) voltage and the (resulting) current is zero.







Q.74. *What do you understand by electrical resonance ?*

Ans. Electrical resonance is said to take place when, on changing *only* the frequency of the alternating e.m.f. (without any change in the magnitude of its peak value), the current in the circuit (and hence, the power consumed in it) suddenly becomes quite large (goes to a maximum) for a particular value of this frequency. We call this frequency as the *resonant frequency* of the given circuit.

Q.75. *What is the condition under which resonance occurs for a series LCR circuit ?*

Ans. Resonance occurs for a series LCR circuit when the frequency of the applied alternating e.m.f. is

$$\nu = \frac{1}{2\pi\sqrt{LC}}$$

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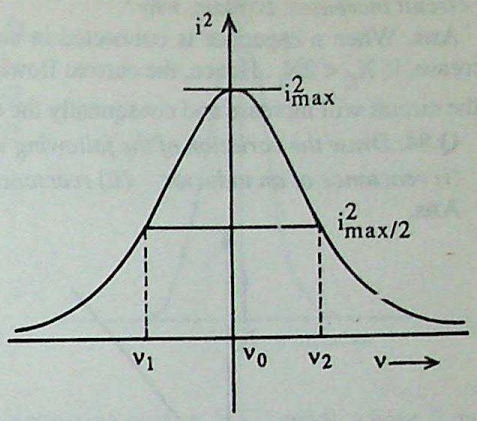
Q.76. *Explain the term "sharpness" of resonance.* **(2)**

Ans. If the square of the current in a series LCR circuit is plotted against the frequency of the applied e.m.f., the graph is of the form shown. The 'maxima' occurs at the resonant frequency of the given circuit.



Let I^2_{max} be the value of the square of the current at the resonant frequency. If we now draw a line at $I^2 = \frac{I^2_{max}}{2}$, parallel to the frequency axis, it cuts the graph at two points.

Let the values of frequency, corresponding to these two points, be ν_1 and ν_2.

The ratio $S = \dfrac{\nu_o}{\nu_2 - \nu_1}$

is, then taken as a measure of the sharpress of resonance of the circuit. The more the value of S, the more sharp is the resonance of circuit.

Q.77. *Discuss how the sharpness of resonance varies with resistance in a series L-C-R circuit ?* **(2)**

Ans. It turns out that the sharpness of resonance of a circuit is given by $\left(\dfrac{2\pi\nu_0 L}{R}\right)$ or $\left(\dfrac{\dfrac{1}{2\pi\nu \cdot c}}{R}\right)$ or $\dfrac{\sqrt{L/C}}{R}$. It is, thus, inversely proportional to the resistance R of the circuit. Thus, the less the resistance in a series LCR circuit, the more sharp its resonance is. We, therefore, need to keep the resistance in a series LCR circuit at as low a value a possible if we wish to increase its sharpness of resonance.

Q.78. *What do you understand by 'quality factor' of a series L-C-R circuit ?* **(1)**

Ans. The *quality factor* (Q) of a series LCR circuit is given by

$$Q = \frac{\omega_o L}{R} = \frac{(1/\omega_0 C)}{R},$$

where $\omega_0 = 2\pi\,\nu_0 = \dfrac{1}{\sqrt{LC}}$ = resonant angular frequency of the given series LCR circuit.

A large value of Q implies (i) a large voltage magnification and (ii) an improved sharpness of reasonance of the circuit. The *Quality factor* of a circuit is, thus, an indicator of the voltage magnification obtainable from it as well as the extent of its sharpness of reasonance.

Q.79. *Give the phase difference between the applied a.c. voltage and the current in an L-C-R circuit at resonance.* **(CBSE 1997) (1)**

Ans. Zero.

Q.80. *An ideal inductor is in turn put across 220 V, 50 Hz and 220 V, 100 Hz supplies. Will the current flowing through it in the two cases be the same or different?* **(CBSE 1998) (1)**

Ans. Current flowing through it will be different.

Q.81. *What is power factor of LCR circuit at resonance?* **(CBSE 1998) (1)**

Ans. one

Q.82. *What is the phase difference between the voltage across an inductor and a capacitor in an a.c. circuit?* **(CBSE 1999) (1)**

Ans. 180°

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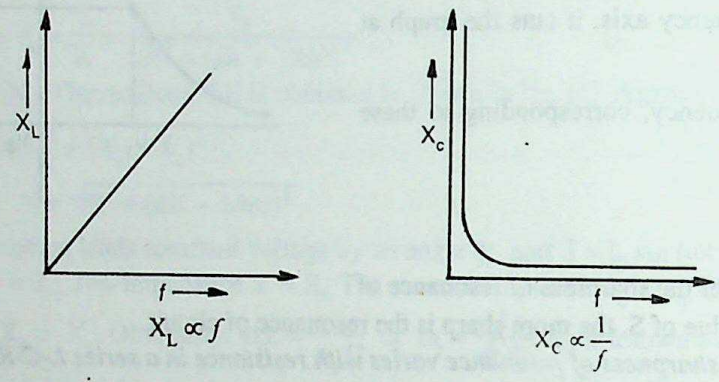
Q.83. *When a capacitor is connected in series with a series L-R circuit, the alternating current flowing in the circuit increases. Explain, why?* **(CBSE 1998)**

Ans. When a capacitor is connected in series with a series L-R circuit, the impedance of the circuit will decrease, if $X_C < 2X_L$. Hence, the current flowing in the circuit will increase. However, if $X_C > 2X_L$, independent of the circuit will increase and consquently the current flowing in the circuit will decrease.

Q.84. *Draw the variation of the following with the frequency of the a.c. source.*

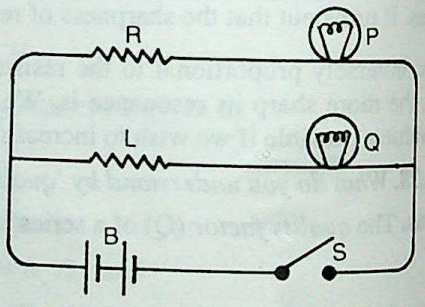
(i) reactance of an inductor (ii) reactance of a capacitor **(CBSE 1997, 199**

Ans.



Q.85. *The given figure shows an inductor L and resistor R connected in parallel to a battery B through a switch S. The resistance of R is the same as that of the coil that makes L. Two identical bulbs, P and Q are put in each arm of the circuit as shown. When S is closed, which of the two bulbs will light up earlier. Justify your answer.*

(CBSE 1998) (2)



Ans. The current in arm containing resistance R and bulb P flows instantaneously over closing OP switch S, whereas the current in the arm containing Q and L starts to rise exponentially on closing of switch S due to presence of inductor L. Therefore bulb P lights up earlier than bulb Q.

Q.86. *A rectangular coil of N turns, area A is held in a uniform magnetic field B. If the coil is rotated at a steady angular speed ω, deduce an expression for the induced e.m.f. in the coil at any instant of time.*

(CBSE 1999) (2

Ans. $e = -\frac{d}{dt}(\phi) = -\frac{d}{dt}(B.A.) = -\frac{d}{dt} BA\cos\omega t \Rightarrow e = BA\omega \sin\omega t$

For a coil of N turns.

$e = NBA\omega \sin\omega t$.

Q.87. *A rectangular coil of N turns and area of cross section A, is held in a time varying magnetic field given by $B = B_0 \sin\omega t$, with the plane of the coil normal to the magnetic field. Deduce an expression for the e.m.f. induced in the coil.*

(CBSE 2000) (2

Ans. Given $B = B_0 \sin\omega t$

$$\phi = BA = AB_0 \sin\omega t$$

$$e = -\frac{d\phi}{dt} = -\frac{d}{dt} AB_0 \sin\omega t = -B_0 A\omega \cos\omega t$$

For a coil of N turns

$$e = -NB_0 A\omega \cos\omega t = -e_0 \cos\omega t,$$

where $e_0 = NB_0 A\omega =$ peak value of induced e.m.f.

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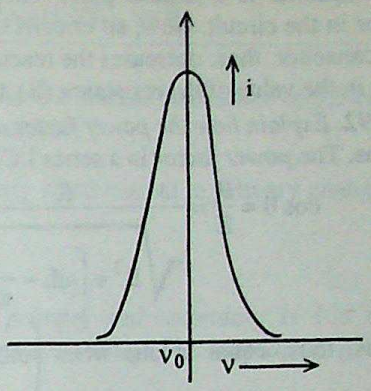
Q.88. *Draw a graph showing variation of current amplitude with the frequency of applied a.c. if resistance of the series L-C-R circuit is low.* **(1)**

Ans. The shape of the graph showing the variation of the current amplitude with frequency for a low resistance series L-C-R circuit is as shown. This graph shows that such a circuit has a very good sharpness of resonance.



Q.89. *Prove that the power absorbed by a coil traversed by alternating current is E I cos θ, where E and I are the root mean square value of e.m.f. and the current and θ their phase difference. What is wattless current ?* **(3)**

Ans. Let I be the instantaneous current in the circuit corresponding to an applied alternating e.m.f. V where

$$V = V_0 \sin \omega t$$

Since, θ is the phase difference between the current and the voltage, we have

$$I = I_0 \sin (\omega t - \theta)$$

$\therefore$ Instantaneous power $= P = VI = V_0 I_0 \sin \omega t \quad \sin (\omega t - \theta)$

$$\therefore \text{Average power} = \frac{1}{T}\int_0^T P\,dt = \frac{V_0 I_0}{T}\int_0^T \sin \omega t \sin (\omega t - \theta)\, dt$$

$$\text{Now, } \int_0^T \sin \omega t \sin (\omega t - \theta)\, dt = \int_0^T \left(\sin^2 \omega t \cos \theta - \frac{\sin 2\omega t}{2} \sin \theta\right) dt$$

$$= \cos \theta \int_0^T \sin^2 \omega t\, dt - \frac{\sin \theta}{2}\int_0^T \sin 2\omega t\, dt$$

$$= \frac{\cos \theta}{2}\int_0^T (1 - \cos 2\omega t).\, dt - \frac{\sin \theta}{2}\int_0^T \sin 2\omega t\, dt$$

But, $\int_0^T \sin 2\omega t\, dt = \int_0^T \cos 2\omega t\, dt = 0$ and $\int_0^T dt = T$. Hence,

$$\text{Average power} = \frac{V_0 I_0}{T} \cdot \frac{\cos \theta}{2} \cdot T = \frac{1}{2} V_0 I_0 \cos \theta = \frac{V_0}{\sqrt{2}} \frac{I_0}{\sqrt{2}} \cos \theta$$

$$= V_{r.m.s.}\, I_{r.m.s.} \cos \theta$$

This is the required relation for the average power.

A *wattless current* is the current in a circuit for which the average power consumed (from the source of alternating e.m.f.) over one cycle is zero.

Q.90. *What are the maximum and minimum values of the power factor for an a.c. circuit ?* **(1)**

Ans. The maximum value of the power factor (= cos θ) is *one* while its minimum value is *zero.*

Q.91. *Power factor can often be improved by the use of a capacitor of appropriate capacitance in the circuit. Is this statement true ?* **(1)**

Ans. Yes. The power factor is *given by the ratio R/Z,* where R is the resistance and $Z = \sqrt{(\text{resistance})^2 + (\text{reactance})^2}$; the total impedance of the circuit.

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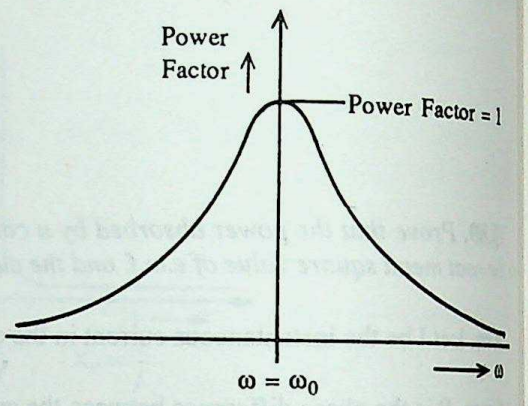
A capacitor is a (almost pure) *reactive* element that acts in opposition to the reactive impedance of the inductor in the circuit. Now, all circuits have a self inductance, however small, associated with it. The addition of the capacitor, thus, decreases the reactance, and hence, the total impedance (Z) of the circuit. There being a change in the value of the resistnace (R), the power factor (=R/Z) goes up.

Q.92. *Explain how the power factor a series L-C-R circuit varies as frequency of applied a.c. is varied?*

Ans. The *power factor* in a series LCR circuit is given by

$$\cos\theta = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$$

It is, thus, equal to one when $\left(\omega L - \frac{1}{\omega C}\right) = 0$, i.e., when $\omega = \omega_0 = \frac{1}{\sqrt{LC}}$. For values of ω on either side of ω_0, the power factor decreases and tends to zero as $\omega \to \pm\infty$. The term involving ω being a squared term, the variation of power factor, on either side of $\omega = \omega_0$, takes place in a symmetrical manner. The nature of the graph is, therefore, as shown.



Q.93. *Why can we say that a choke coil is almost a wattless impedance ?*

Ans. For a *choke coil* (a series LR circuit), the power factor is $\frac{R}{\sqrt{R^2 + \omega^2 L^2}}$.

Now here we try to keep R as low as possible. The inductance L (and hence, the inductive impedance = ωL) is, however, kept quite large. The power factor is, therefore, almost $R/\omega L$ which is very small because $R \ll \omega L$. The choke coil is, therefore, almost, a wattless impedance.

Q.94. *A series LR circuit is being run on an alternating e.m.f. and the impedance of the inductor alone (= ωL) is twice that of the resistor (R) in the circuit. If a capacitance C of impedance half that of the inductor were to be added in series with the circuit, show that the power factor of the circuit goes up by nearly 58%.*

Ans. When a capacitor of impedance half that of inductor is added in series to the LR circuit, the total impedance of the circuit now is

$$Z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2} = \sqrt{R^2 + (2R - R)^2} = \sqrt{2}R$$

($\because$ $\omega L = 2R$ (given) and, therfore, $\frac{1}{\omega C} = \frac{1}{2}\omega L = R$)

The new power factor of the circuit is, therefore, $\frac{R}{(\sqrt{2}R)} = \frac{1}{\sqrt{2}}$

Before the capacitor was added, the total impedance of the coil was

$$\sqrt{R^2 + (\omega L)^2} = \sqrt{R^2 + (2R)^2} = \sqrt{5}\,R$$

The power factor of the circuit was, therefore, $\frac{R}{\sqrt{5}R} = \frac{1}{\sqrt{5}}$

The factor by which the power factor goes up is $\left(\frac{1}{\sqrt{2}}\right) \div \left(\frac{1}{\sqrt{5}}\right) = \sqrt{\frac{5}{2}} = \sqrt{2.5} \approx \mathbf{1.58}$

The percentage increases, therefore, 58%.

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SOLVED NUMERICAL PROBLEMS ON UNIT – VI B

Example 1. *The primary and secondary coils of a transformer have a mutual inductance of 0.5 H. What is induced e.m.f. in secondary when the current in the primary changes at $5As^{-1}$?*

Solution : Let $|e_s|$ be the magnitude of induced e.m.f. in secondary when current in primary changes at $\frac{dI_1}{dt}$.

Then $|e_s| = M \frac{dI_1}{dt} = 0.5 \times 5 = \mathbf{2.5\ V}$.

Example 2. *In a ideal transformer the number of turns in primary and secondary is 100 and 2000 respectively. If maximum voltage in primary is 120 V, what is maximum voltage in secondary ? If current in primary is 20 A, what is current in secondary?*

Solution : In an ideal transformer

$$\frac{V_s}{V_p} = \frac{I_p}{I_s} = \frac{n_s}{n_p}$$

Given $V_p = 120\ V;\ n_s = 2000;\ n_p = 100;\ I_p = 20\ A$

$$\therefore \quad V_s = \left(\frac{n_s}{n_p}\right) V_p = \left(\frac{2000}{100}\right) \times 120 = \mathbf{2400\ V}$$

and $$I_s = I_p \left(\frac{n_p}{n_s}\right) = 20 \left(\frac{100}{2000}\right) = \mathbf{1\ A}$$

Example 3. *A step-up transformer has a transformer ratio of 10. The input voltage is 220 V. The output voltage runs a device of power 4.4 kW. Assuming efficiency of transformer to be 80%. What is (i) voltage in secondary, (ii) current in secondary (iii) current in primary and (iv) input power ?*

Solution : Let n be transformer ratio.

We know $V_s/V_p = n. = 10$ (given), $V_p = 220\ V$

(i) $\therefore V_s = 220 \times 10 = \mathbf{2200\ V}$

(ii) The *output power* P_o of transformer is 4.4 kW.

$\because V_s \cdot I_s = 4.4 \times 10^3$

or $I_s = 4.4 \times 10^3 / 2200 = \mathbf{2\ A}$

(iii) $\eta =$ (output power) / (input power) $= P_o / P_I$

$$\therefore \quad P_I = P_0/\eta = \frac{(4.4 \times 10^3)}{0.8} = 5.5 \times 10^3\ W = \mathbf{5.5kW}$$

(iv) Let I_p be the input current. We know $P_I = I_p \cdot V_p$

or $5.5 \times 10^3 = I_p \times 220$

$\therefore I_p = 5.5 \times 10^3 / 220 = \mathbf{25\ A}$.

Example 4. *The output voltage of an ideal transformer, connected to a 240 V a.c. mains is 24 V. When this transformer is used to light a bulb with rating 24 V, 24 W, calculate the current in the primary coil of the circuit.* **(CBSE 2000)**

Solution: Here $N_1 = 240\ V,\ V_2 = 24\ V$

$$I_2 = \frac{P}{V_2} = \frac{24}{24}\ A = 1A$$

For an ideal transformer

$$I_1 V_1 = I_2 V_2 \Rightarrow I_1 = \frac{I_2 V_2}{V_2} = \frac{1 \times 24}{240} = \mathbf{0.1\ A}.$$

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Example 5. *The area of each turn of a 1000 turns coil of an a.c. generator is 0.27 m^2. If the coil is made to rotate at 2000 rpm in a magnetic field of 0.1 T, what is the maximum value of the alternating voltage induced in the coil.*

Solution : We have $E_{max} = nAB\omega$

Here n = 1000, A = 0.27 m^2, B = 0.1 T and $\omega = \left(2000 \times \frac{2\pi}{60}\right)$ radian per second.

Hence, $E_{max} = 1000 \times 0.27 \times 0.1 \times \frac{2000 \times 2\pi}{60}$ V = **5652 V.**

Example 6. *A voltmeter reads 100V when connected across the terminals of a sinusoidal power supply of 1 kHz. Write down the equation for the instantaneous voltage of the source.*

Solution : The voltmeter reads the r.m.s. or effective value of voltage, Let e_o be the peak value of voltage.

Then $e_{r.m.s} = \frac{e_o}{\sqrt{2}}$ or $100 = \frac{e_o}{\sqrt{2}}$ or $e_o = 141.2$ V. Also ν = 1 kHz = 1000 Hz. The instantaneous voltage of the supply is $e = e_0 \sin \omega t = e_o \sin 2\pi\nu t$ = **141.2 sin 2000 πt.**

Example 7. *A voltage e = 60 sin 120 πt volt is applied across a 30 Ω resistance. An a.c., ammeter is connected in series with the resistor. What is the reading of ammeter?*

Solution : The a.c. ammeter will read the r.m.s. value of current and $I_{r.m.s} = e_{r.m.s} / R$.

Also, $e_{r.m.s} = e_o/\sqrt{2} = 60/\sqrt{2} = 42.49$ V

$\therefore \quad I_{r.m.s} = 42.49/30 \approx$ **1.416A.**

Example 8. *In India, domestic a.c. is supplied at 220 V, 50 Hz. What is (i) peak value (ii) peak-to-peak value of voltage and (iii) instantaneous voltage?*

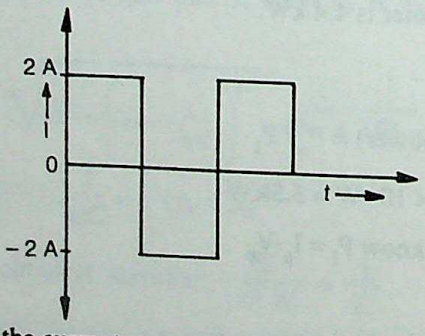
Solution : Let e_o be the peak value of voltage. Then $e_o = \sqrt{2}\ e_{r.m.s} = 1.412 \times 220 =$ **310 V.**

(ii) The peak-to-peak voltage is $2\ e_o =$ **620 V.**

(iii) The instantaneous voltage is $e = e_o \sin \omega t = e_o \sin 2\pi\nu t$

$\therefore$ **$e = 310 \sin 100\ \pi\ t$.**

Example 9. *Calculate the r.m.s. value of the alternating current shown in the figure.*



Solution: The r.m.s. value of the current. **(CBSE 1998)**

$$= \sqrt{\frac{1}{T}\left[2^2 \cdot t\right]_0^{T/2} + \frac{1}{T}\left[(-2)^2 t\right]_{T/2}^{T}} = \sqrt{\frac{1}{T} 4 \cdot \frac{T}{2} + \frac{1}{T} 4 \cdot \left(T - \frac{T}{2}\right)} = \sqrt{2+2} = \mathbf{2\ A.}$$

Here, T is the time period.

Example 10. *An electric heater and an electric bulb are rated 500 W, 220 V and 100 W, 220 V respectively. Both are connected in series to a 220 V a.c. mains. Calculate the power consumed by (i) the heater (ii) electric bulb.*

Solution: We have **(CBSE 1997)**

$P_h = 500$ W, $V_h = 220$ V, $P_b = 100$ W, $V_b = 220$ V

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Resistance of heater, $R_h = \frac{V_h^2}{P_h} = \frac{(220)^2}{500}\ \Omega = 96.8\ \Omega$

Resistance of the bulb, $R_b = \frac{V_b^2}{P_b} = \frac{(220)^2}{100}\ \Omega = 484\ \Omega$

Resistance across a.c. mains $= R_h + R_b = (96.8 + 484)\ \Omega = 580.8\ \Omega$

r.m.s. value of the current in the circuit, $I_{rms} = \frac{V_{r.m.s.}}{R} = \frac{220}{580.8}\ A = 0.38\ A$

(i) $\therefore$ Power consumed by the heater $P_h' = I_{r.m.s.}^2 \cdot R_h = (0.38)^2 \times 96{\cdot}8 = 13.97\ W \approx \mathbf{14\ W}$

(ii) Power consumed by the bulb $P_b' = I_{r.m.s.}^2 \cdot R_b = (0.38)^2 \times 484 = 69.88\ W = \mathbf{69.9\ W}$

Example 11. *The instantaneous voltage from an a.c. source is given by E = 300 sin 314 t. What is the r.m.s. voltage of the source?* **(CBSE 2000)**

Solution: $E_{rms} = \frac{E_0}{\sqrt{2}} = \frac{300}{\sqrt{2}}\ V = \mathbf{212.7\ V}.$

Example 12. *An a.c. current in a 100 Ω resistance produces heat at 3 kW. What is the effective value of current and voltage?*

Solution : In a resistance, the heat produced P is given by

$$P = I_{r.m.s}^2 \times R$$

or $$3000 = I_{r.m.s}^2 \times 100$$

$\therefore$ $$I_{r.m.s} = \sqrt{30} = \mathbf{5.477\ A}$$

The r.m.s. or effective value of voltage is given by $e_{r.m.s.} = I_{r.m.s.} \times R = 5.477 \times 100 = \mathbf{547.7}$ V.

Example 13. *An A.C. voltage represented by e = 310 sin (100 πt) is applied across a resistor of resistance 155 Ω. Write the equation for the instantaneous current in the resistor. What are the peak and r.m.s values of this current?*

Solution : For a resistor, there is no phase difference between the current and voltage. Also the impedance is just equal to the value of the resistance which, in this case, is 155Ω.

Hence, $I = \frac{e}{Z} = \frac{310}{155} \sin(100\pi t) = 2\sin(100\pi t)$

Thus, the peak value of the current is 2A. Its r.m.s. value is $\left(\frac{2}{\sqrt{2}}\right) A = \sqrt{2}\ A = \mathbf{1.414\ A}.$

Example 14. *An inductance of 2 mH is connected across an oscillator having effective value of p.d. as 100 V. What is current amplitude at a frequency of (i) 50 Hz (ii) 10 kHz ?*

Solution : Let e_o be the maximum value of p.d. of oscillator.

Then, $e_o = \sqrt{2}\ e_{r.m.s} = 1.412 \times 100 = 141.2$ V

(i) The reactance X_L of inductance at $\nu = 50$ Hz is

$X_L = 2\pi\nu L = 2 \times 3.142 \times 50 \times 2 \times 10^{-3} = 0.628\ \Omega$

The current amplitude, $I_o = e_o / X_L = 141.2/0.628\ A = \mathbf{224.8\ A}.$

(ii) The reactance X_L of inductance at $\nu = 10$ kHz is $X_L = 2 \times 3.142 \times 10^4 \times 2 \times 10^{-3} = 125.68\ \Omega$

The current amplitude $I_o = e_o / X_L = 141.2 / 125.68 = \mathbf{1.12A}.$

Note the drastic change in current amplitude as frequency of applied a.c. becomes high.

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Example 15. *Find the maximum value of current when an inductance of one henry is connected to an a.c. source of 200 volts, 50 Hz.* **(CBSE 1995 Comptt.)**

Solution : We have r.m.s. value of voltage = 200 volt.

Also, $\omega = 2\pi\nu = 2\pi \times 50 = 100\pi = 314.2\ s^{-1}$

$\therefore$ Impedance of the inductor = $\omega L = 314.2 \times 1\Omega = 314.2\Omega$

$\therefore$ r.m.s. value of current = $\dfrac{200}{314.2}$ A = 0.637 A

$\therefore$ Peak value of current = $0.637 \times \sqrt{2}$ A = **0.900 A.**

Example 16. *A coil has an inductance of 1 henry. (a) At what frequency will it have a reactance of 3142Ω (b) What should be the capacity of a capacitor which has the same reactance at that frequency?* **(CBSE 1995 Comptt.)**

Solution : (a) Let ν be the required frequency. Then $\omega L = 2\pi\nu L = 3142\ \Omega$

$$\therefore \quad \nu = \frac{3142}{2\pi \times 1}\ \text{Hz} = \frac{3142}{2 \times 3.141}\ \text{Hz} = \mathbf{500\ Hz}$$

Thus, the required frequency is 500 Hz.

(b) Let C be the required capacitance. Then

$$\frac{1}{\omega C} = \frac{1}{2\pi\nu C} = 3142\ \Omega$$

$$\therefore \quad C = \frac{1}{2\pi\nu \times 3142} = \frac{1}{2 \times 3.142 \times 500 \times 3142}\ \text{F}$$

$$= 0.010 \times 10^{-5}\ \text{F} = \mathbf{0.1\mu F.}$$

Example 17. *Obtain the reactance of a capacitor of capacity 0.1 μF at a frequency of (i) 100 Hz (ii) 50 kHz. What is current amplitude at the above two frequencies if r.m.s. value of p.d. is 220 V?*

Solution : The reactance of capacitor

$$X_c = 1/\omega C = 1/2\pi\nu C$$

Given $C = 0.1\ \mu\text{F} = 10^{-7}\ \text{F}$

(i) $\nu = 100$ Hz; $\therefore\ X_c = 1/(2 \times 3.142 \times 10^2 \times 10^{-7})$

$= 15.9 \times 10^3\ \Omega = \mathbf{15.9\ k\Omega}$

(ii) $\nu = 50\ \text{kHz} = 5 \times 10^3$ Hz

$\therefore\ X_c = 1/(2 \times 3.142 \times 5 \times 10^4 \times 10^{-7}) = \mathbf{31.8\ \Omega.}$

Note the reactance of capacitor decreases by an appreciable amount when frequency of applied a.c. is high.

Let e_o be the peak value or amplitude of applied a.c.

Then $e_o = \sqrt{2}\ e_{r.m.s} = \sqrt{2} \times 220 = 311$ V

The current amplitude $I_o = e_o / X_c$. Therefore ,

(i) $I_o = 311/(15.9 \times 10^3) = 19.5 \times 10^{-3}\ \text{A} = \mathbf{19.5\ mA.}$

(ii) $I_o = 311/31.8 = \mathbf{9.77A.}$

Example 18. *A coil of inductance 500 mH has a resistance of 80 Ω . What is the impedance of coil for an a.c. of frequency 60 c.p.s.?*

Solution : The impedance $Z = (R^2 + X_L^2)^{1/2}$ and $X_L = \omega L = 2\pi\nu L = 2 \times 3.142 \times 60 \times 0.5 = 188.5\Omega$

Given R = 80 Ω; therefore, $Z = (80)^2 + (188.5)^2 = (6400 + 35532)^{1/2} = \mathbf{204.7\ ohm.}$

Example 19. *An 80V, 800W heater is to be operated on a 100 V, 50Hz supply. Calculate the inductance of choke required.* **(CBSE 1991)**

Solution : Let I and R be the rated current and resistance of heater.

Obviously, $R = V^2/P = 80 \times 80/800 = 8\Omega$ and $I = V/R = 80/8 = 10\text{A}$

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When heater and inductance L are connected in series across a.c. the effective current must be 10 A. Let Z be impedance of L – R circuit formed by choke and heater coil. Obviously,

$10 = 100/Z \;\therefore\; Z = 10\Omega.$

Now, $Z = (R^2 + X_L^2)^{1/2}$ or $X_L = (Z^2 - R^2)^{1/2} = (100 - 64)^{1/2} = 6\Omega$

Also, $X_L = 2\pi\nu L$ or $L = X_L / 2\pi\nu$ Therefore,

$$L = \frac{6}{2 \times 3.142 \times 50} \text{ H} = 0.0191 \text{ H} = \mathbf{19.1\ mH.}$$

Example 20. *A student connects a long air core coil of manganin wire to a 100 V d.c. source and records a current of 1.5 A. When the same coil is connected across 100V, 50 Hz a.c. source the current reduces to 1.0 A.*

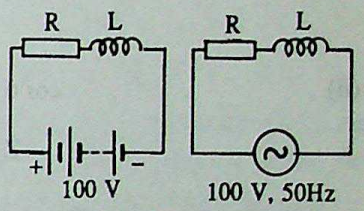
(i) Give reasons for this observation,

(ii) Calculate the value of the reactance of the coil. **(CBSE 1994)**

Solution : Let R and L stand for the resistance and the self inductance, respectively, of the long air core coil of manganin.

(i) For the d.c. source, the total impedance of the coil is just its resistance R. Hence, from the given data,

$$\frac{100}{R} = 1.5 \text{ or } R = \frac{100}{1.5}\Omega = \frac{200}{3}\Omega$$



(ii) For the a.c. source the total impedance is that of a series L-R circuit, *i.e.*, $\sqrt{R^2 + \omega^2 L^2}$.

Hence, for this case, we have

$$\frac{100}{\sqrt{R^2 + \omega^2 L^2}} = 1 \qquad \therefore \sqrt{R^2 + \omega^2 L^2} = \frac{100}{1}\ \Omega = 100\ \Omega$$

$$R^2 + \omega^2 L^2 = 10000$$

$$\therefore \qquad \omega^2 L^2 = X_L^2 = 10000 - \left(\frac{200}{3}\right)^2 = \frac{50000}{9} \text{ ohm}^2$$

or
$$X_L = \frac{\sqrt{5}}{3} \times 10^2\ \Omega = \frac{2.236}{3} \times 10^2\ \Omega$$

$$= 0.745 \times 10^2\ \Omega = \mathbf{74.5\ \Omega}$$

Thus, (i) The current gets reduced with the a.c. source because of the (additional impedance offered to it by the self inductance of the coil and (ii) The reactance X_L (= ωL) of the coil is 74.5 Ω.

Example 21. *Distinguish between reactance and impedance. When a series combination of a coil of inductance L and a resistor of resistance R is connected across a 12 V, 50 Hz supply a current of 0.5 A flows through the circuit. The current differs in phase from applied voltage by π/3 radian. Calculate the value of L and R.* **(CBSE 1997)**

Solution: See theoretical section for first part.

Here, $V_{r.m.s.} = 12$ V, $f = 50$ Hz, $I_{r.m.s.} = 0.5$ A, $\phi = \frac{\pi}{3}$ rad.

We have, $Z = \frac{V_{r.m.s.}}{I_{r.m.s.}} = \frac{12}{0.5}\Omega = 24\ \Omega$ $\cos\phi = \frac{R}{Z} \Rightarrow R = Z\cos\phi = 24 \cos 60^\circ = 12\ \Omega$

$$\tan\phi = \frac{X_L}{R} = \frac{2\pi f \cdot L}{R} \Rightarrow L = \frac{R \tan\phi}{2\pi f} = \frac{12 \tan 60^\circ}{2 \times 3.14 \times 50} = 0.07 \text{ henry}$$

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Example 22. *An a.c. circuit having an inductor and a resistor in series draws a power of 560 W from a a.c. source marked 210 V, 60 Hz. If the power factor of the circuit is 0.8, Calculate: (i) the impedence of the circuit (ii) the inductance of the inductor used.* **(CBSE 1997 Compt.**

Solution: Here, $P = 560$ W, $V_{r.m.s.} = 210$ W, $\nu = 60$ Hz, $\cos\phi = 0.8$

(i) We have, $P = V_{r.m.s.} \cdot I_{r.m.s.} \cos\phi$

Also, $$I_{r.m.s.} = \frac{V_{r.m.s.}}{Z}$$

$\Rightarrow$ $$Z = \frac{V_{r.m.s.}}{I_{r.m.s.}} = \frac{V_{r.m.s.}}{\frac{P}{V_{r.m.s.}\cos\phi}}$$

$$= \frac{V^2_{r.m.s.}\cos\phi}{P}$$

$$= \frac{(210)^2 \times 0.8}{560} = 63\ \Omega$$

(ii) $$\cos\phi = \frac{R}{Z} \Rightarrow R = Z\cos\phi = 63 \times 0.8\ \Omega = 50.4\ \Omega$$

$$Z = \sqrt{R^2 + X_L^2} \Rightarrow X_L = \sqrt{Z^2 - R^2}$$

$$= \sqrt{63^2 - (50.4)^2} = 37.8\ \Omega$$

$$X_L = 2\pi\nu L \Rightarrow L = \frac{X_L}{2\pi\nu} = \frac{37.8}{2 \times 3.14 \times 60} = \mathbf{0.10}\ \text{henry.}$$

Example 23. *Distinguish between reactance and impedance. When the series combination of inductance and resistance are connected with 10 V, 50 Hz a.c. source, a current of 1 A flows through the circuit. The voltage leads current by* $\frac{\pi}{3}$. *Calculate the value of resistance and inductance.*

(CBSE 199

Solution: See theoretical section for first part.

We have, $$Z = \frac{V_{r.m.s.}}{I_{r.m.s.}} = \frac{10}{1} = 10\ \Omega$$

$$\cos\phi = \frac{R}{Z} \Rightarrow R = Z\cos\phi = 10 \times \cos 60 = \mathbf{5\ \Omega}$$

Also, $$\tan\phi = \frac{2\pi fL}{R} \Rightarrow L = \frac{R\tan\phi}{2\pi\nu}$$

$$= \frac{5 \times \tan 60}{2 \times 3.14 \times 50} = \frac{5 \times \sqrt{3}}{2 \times 3.14 \times 50} = \mathbf{0.027\ henry.}$$

Example 24. *An A.C. source of 100 V r.m.s., 50 Hz is connected across a 20* Ω *resistor and a 2 mH inductor in series. Calculate (i) impedance of the circuit (ii) r.m.s current in the circuit.*

(CBSE 199

Solution : Given, $e_{r.m.s} = 100$ V, $\nu = 50$ Hz.

$$\omega = 2\pi\nu = 100\,\pi \text{ radian } s^{-1}$$

$\therefore$ $$\omega L = 100\pi \times 2 \times 10^{-3}\ \Omega = \frac{\pi}{5}\Omega = \frac{3.142}{5}\Omega = 0.628\ \Omega \approx 0.63\ \Omega$$

Also, $$R = 20\ \Omega$$

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(i) $Z = \sqrt{R^2 + \omega^2 L^2} = \sqrt{20^2 + (0.63)}$

$= \sqrt{400 + 0.4} = \mathbf{20\ \Omega}$

(ii) The r.m.s. current through the circuit is

$$I_{r.m.s} = \frac{E_{r.m.s}}{Z} = \frac{100}{20}\ A = 5\ A.$$

Example 25. *A 10 μF capacitor is in series with a resistance of 120 Ω. The combination is connected to an a.c. of 220 V, 50 Hz. What is (i) capacitative reactance (ii) the impedance (iii) the power factor (iv) the phase difference between current and applied voltage,?*

Solution : $C = 10\mu F = 10^{-5}$ F; $\nu = 50$ Hz

(i) $\therefore\ X_c = 1/(2\pi\nu C) = \dfrac{1}{(2 \times 3.142 \times 50 \times 10^{-5})} = \mathbf{318.3\ \Omega}$

(ii) $Z = (R^2 + X_c^2)^{1/2} = ((120)^2 + (318.3)^2)^{1/2} = (115524)^{1/2} = \mathbf{339.9\ \Omega}$

(iii) The power factor $\cos\phi = R / Z$

$\therefore \cos\phi = 120 / 339.9 = \mathbf{0.353}$

(iv) $\phi = \cos^{-1}(0.353) = \mathbf{69.326^\circ}$.

Example 26. *When an alternating voltage of 200 V is applied across a device X, a current of 0.5 A flows through the circuit and is in phase with the applied voltage. When the same voltage is applied across another device Y, the same current again flows through the circuit but it leads the applied voltage by $\frac{\pi}{2}$ radians.*

(i) Name the device X and Y.

(ii) Calculate the current flowing in the circuit when same voltage is applied across the series combination of X and Y. **(CBSE 1997)**

Solution: (i) The phase difference between the applied voltage and current suggests that X is a resistor and Y a capacitor.

(ii) Here, I = 0.5 A for both devices

$$\therefore R = X_C = \frac{V}{I} = \frac{200}{0.5} = 400\ \Omega$$

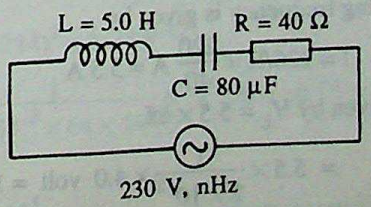
$$I_{r.m.s.} = \frac{V_{r.m.s.}}{\sqrt{R^2 + X_C^2}} = \frac{200}{\sqrt{(400)^2 + (400)^2}} = \frac{200}{400\sqrt{2}} = \mathbf{0.35\ A.}$$

Example 27. *A variable frequency 230 V alternating voltage source is connected across a series combination L = 5.0 H, C = 80 μf and R = 40 Ω. Calculate :*

(i) the angular frequency of the source which drives the circuit in resonance.

(ii) amplitude of the current at resonating frequency.

(iii) r.m.s. potential drop across the inductor at resoning frequency. **(CBSE 1994)**



Solution : Let ν be the frequency of the 230 V a.c. source. The corresponding angular frequency ω is given by $\omega = 2\pi\nu$

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(i) Resonance is obtained when $X_L = X_C$. Hence, if ω_c be the angular frequency of the source which drive the circuit in reasonance, we have, $\omega_c L = \dfrac{1}{\omega_c C}$ or $\omega_c = \dfrac{1}{\sqrt{LC}}$

Substituting values, we get

$$\omega_c = \frac{1}{(5.0 \times 80 \times 10^{-6})^{1/2}} s^{-1} = \frac{1}{20 \times 10^{-3}} s^{-1} = \mathbf{50\ s^{-1}}$$

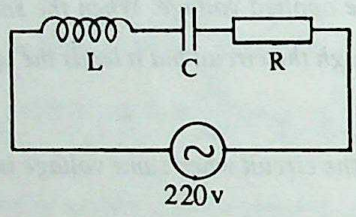
(ii) At the resonating frequency $\left[\nu_c = \dfrac{\omega_C}{2\pi} = \dfrac{50}{2\pi} \text{Hz}\right]$ the impedance Z of the circuit is equal to R. Hence, the amplitude of the current I_O at the resonating frequency, is given by

$$I_o = \frac{230\sqrt{2}\ V}{40\Omega} = 5.75\sqrt{2}\ A = \mathbf{8.12\ A}$$

(iii) The r.m.s potential drop across the inductor at the resonating frequency is given by $V_L = I_{r.m.s} \times \omega_c L$:

$5.75 \times 50 \times 5V = 5.75 \times 250\ V = \mathbf{1437.5\ V.}$

Example 28. *Figure below shows a series LCR circuit connected to a variable frequency 220 V source: L = 4.0H, C = 100 μF and R = 40 Ω (i) Calculate the resonant frequency of the circuit.*
(ii) Obtain the impedance of the circuit and the amplitude of the current at the resonating frequency.
(iii) Determine the r.m.s. potential drop across the inductor. **(CBSE 1995**



Solution : (i) The resonant frequency of a series LCR circuit is given by

$$\nu = \frac{1}{2\pi}\frac{1}{\sqrt{LC}}$$

Now, $LC = 4.0 \times 100 \times 10^{-6}\ s^2 = 4 \times 10^{-4}$

$\Rightarrow$ $\sqrt{LC} = 2 \times 10^{-2}$

$\therefore$ $\nu = \dfrac{1}{2\pi \times 2 \times 10^{-2}} s = \dfrac{25}{\pi} s^{-1} = \mathbf{7.96\ s^{-1}}$

(ii) At the resonant frequency, the impedance of a series LCR circuit equals its resistance only. Hence, at the resonating frequency, we have impedance = R = **40 Ω**

$\therefore$ r.m.s. current at resonant frequency

$$= \frac{220}{40} A = 5.5\ A$$

Hence, amplitude of current at this frequency = $5.5\sqrt{2} \approx 7.78$ A

(iii) The r.m.s. current at the resonating frequency is given by

$$I = 220/R = \frac{220}{40} A = 5.5\ A$$

$\therefore$ r.m.s. potential drop across L is given by $V_L = 5.5 \times \omega L$

$$= 5.5 \times \frac{1}{2 \times 10^{-2}} \times 4.0 \text{ volt} = 11 \times 10^2 \text{ volt} = \mathbf{1100\ volt}$$

$$\left(\text{Note : } \omega = \frac{1}{\sqrt{LC}} = \frac{1}{2 \times 10^{-2}} s^{-1}\right)$$

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Example 29. *A 25.0 μF capacitor, a 0.10 henry inductor and a 25.0 Ω resistor are connected in series with an a.c. source whose e.m.f is given by E = 310 sin 314t.*

(i) What is the frequency of the e.m.f.?

(ii) Calculate:

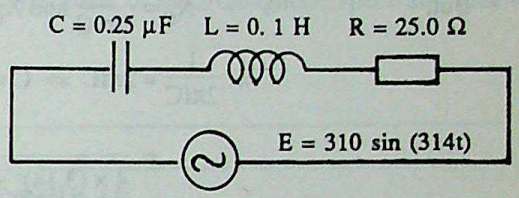
(a) the reactance of the circuit.

(b) the impedance of the circuit and

(c) the current in the circuit.

(CBSE 1995 Comptt.) (5)

Solution : The required circuit is as shown below. Here we have



(i) $\nu = \frac{\omega}{2\pi}$ and $\omega = 314$ $\quad \therefore \nu = \frac{314}{2 \times 3.142} \sim$ **50 Hz**

(ii) (a) The reactance, X of the circuit is $\left(\omega L - \frac{1}{\omega C}\right)$

Here, $\omega L = 314 \times 0.1\ \Omega = 31.4\ \Omega$

$$\frac{1}{\omega C} = \frac{1}{314 \times 25 \times 10^{-6}}\ \Omega = \frac{10^6}{7850}\ \Omega = \mathbf{127.4\ \Omega}$$

$$\therefore \quad X = \left(\omega L - \frac{1}{\omega C}\right) = (127.4 - 31.4) = \mathbf{96\ \Omega}$$

This reactance will show a capacitative behaviour.

(b) The impedance, Z, of the circuit is given by

$$Z = \sqrt{R^2 + X^2} = \sqrt{(25)^2 + (96)^2} = \sqrt{625 + 9216} = \sqrt{9841}\ \Omega = \mathbf{99.2\ \Omega}$$

(c) The current in the circuit will have a peak value equal to $E/Z = \left(\frac{310}{99.2}\right) A = \mathbf{3.125\ A}$

Example 30. *In a series L-C-R circuit, the voltage across an inductor, capacitor, and resistor are 40 V, 20 V and 20 V respectively. Wht is the total voltage operative across the combination?* **(CBSE 1998)**

Solution: Here, $V_L = 40$ V, $V_C = 20$ V, $V_R = 20$ V

Total voltage across the combination,

$$V = \sqrt{V_R^2 + (V_L - V_C)^2}$$

$$= \sqrt{20^2 + (40 - 20)^2} = \sqrt{400 + 400} = 20\sqrt{2} = \mathbf{28.28\ V.}$$

Example 31. *A radio can tune over the frequency range of a portion of MW (medium wave) broadcast band (800 kHz to 1200 kHz). If its L-C circuit has an effective inductance of 200 μH, what must be the range of its variable capacitor?*

Solution : The frequency of oscillations of L-C circuit is $\nu = \frac{1}{2\pi\sqrt{LC}}$. If C is large ν is small and vice-versa. Let C_{max} and C_{min} be the maximum and minimum value of capacitor required over given range. Then

$$\nu_{min} = 800 \times 10^3\ \text{Hz} = \frac{1}{[2 \times 3.142 \times (2 \times 10^{-4}\ C_{max})^{1/2}]}$$

or $$64 \times 10^{10} = 1/(6.284)^2 \times 2 \times 10^{-4}\ C_{max}$$

$\therefore$ $$C_{max} = \frac{1}{(6.284)^2 \times 64 \times 10^6}\ F = 3.9 \times 10^{-10}\ F = \mathbf{3.9 \times 10^{-10}\ F}$$

Similarly,

$$\nu_{max} = 12 \times 10^5 = \frac{1}{2 \times 3.142 \times (2 \times 10^{-4} \times C_{min})^{1/2}}$$

or $$C_{min} = 1/(6.284)^2 \times 2 \times 10^{-4} \times 144 \times 10^{10}\ F = 0.88 \times 10^{-10}\ F = \mathbf{88pF}$$

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Example 32. *Draw the curve showing variation of inductive reactance and capacitive reactance with applied frequency of an a.c. source.*

A capacitor, resistor of 5Ω and an inductor of 50 mH are in series with an a.c. source marked 100 V, 50 Hz. It is found that voltage is in phase with the current. Calculate the capacitance and the impedance of the circuit. **(CBSE 1999)**

Solution: See theoretical section for 1st part.

Here, $R = 5\Omega$, $L = 50\ mH = 5 \times 10^{-2}$ H, $\nu = 50$ Hz.

As voltage is in phase with current $\therefore\ X_C = X_L$

But, $$X_C = \frac{1}{2\pi\nu C} \text{ and } X_L = 2\pi fL$$

$$\Rightarrow \frac{1}{2\pi fC} = 2\pi fL \Rightarrow C = \frac{1}{4\pi^2 f^2 L}$$

$$= \frac{1}{4 \times (3.14)^2 \times (50)^2 \times 5 \times 10^{-2}} = 2 \times 10^{-4}\ F = \mathbf{200\ \mu F}.$$

Impedance $Z = R = \mathbf{5\ \Omega}$

Example 33. *Sketch the variation of inductive reactance and capacitative reactance with the frequency of the a.c. source.*

A 100 mH .inductor, a 20 μF capacitor and a 10 Ω resistor are connected in series to a 100 V, 50 Hz a.c. source. Calculate:

(i) Impedance of the circuit at resonance

(ii) Current at resonance

(iii) Resonant frequency. **(CBSE 2000)**

Solution: See theoretical section for 1st part.

Here, $L = 100\ mH = 0.1$ H, $C = 20\ \mu F = 2 \times 10^{-5}$ F

$R = 10\ \Omega$, $V_{eff} = 100$ V, $\nu = 50$ Hz.

(i) At resonance, $Z = R = \mathbf{10\ \Omega}$

(ii) $$I_{eff.} = \frac{V_{eff}}{Z} = \frac{100}{10}\ A = \mathbf{10\ A}$$

(iii) $$\nu_r = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2 \times 3.14\sqrt{0.10 \times 2 \times 10^{-5}}} = \frac{1}{2 \times 3.14 \times 1.41 \times 10^{-3}} = 0.1129 \times 10^3 = 112.9\ Hz.$$

Example 34. *For a given a.c. circuit, distinguish between resistance, reactance and impedance. An a.c. source of frequency 50 Hz is connected to a 50 mH inductor and a bulb. The bulb glows with some brightness. Calculate the capacitance of the capacitor to be connected in series with the circuit so that the bulb glows with maximum brightness.* **(CBSE 2000)**

Solution: See theoretical section for 1st part.

Here, $f = 50$ Hz, $L = 50\ mH = 5 \times 10^{-2}$ H

When the circuit is in resonance, the bulb will glow with maximum brightness.

At resonance, $X_L = X_C$

$$\Rightarrow 2\pi\nu L = \frac{1}{2\pi\nu C}$$

$$\Rightarrow \quad C = \frac{1}{4\pi^2\nu^2 \cdot L} = \frac{1}{4 \times (3.14)^2 \times (50)^2 \times 5 \times 10^{-2}} = 2.0 \times 10^{-4}\ F = \mathbf{200\ \mu F}.$$

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UNIT - VII

ELECTROMAGNETIC WAVES

CBSE SYLLABUS CONTENTS

History of electromagnetic waves (Maxwell, Hertz, Bose, Marconi). Electromagnetic spectrum (radio, micro-waves, infrared, optical, ultraviolet, X-rays, and gamma rays) including elementary facts about their uses and propagation properties of the atmosphere w.r.t. various parts of electromagnetic spectrum, green house effect.

No. of periods allotted : 7 out of 168

No. of marks allotted : 7 out of 70

BASIC FACTS AND FORMULAE

In 1865 James Clark Maxwell, on the basis of four basic results of electricity and magnetism, theoretically predicted existence of *electromagnetic waves.* In 1887, Heinrich Hertz produced and detected electromagnetic waves. Electromagnetic waves consist of oscillating electric and magnetic fields. The fields are mutually perpendicular and also perpendicular to direction of wave propagation. Electromagnetic waves are transverse in nature.

Properties of Electromagnetic Waves

(1) Electromagnetic waves consists of oscillating and mutually perpendicular electric and magnetic fields.

(2) The direction of E and B is perpendicular to direction of wave propagation, i.e., electromagnetic waves are transverse in nature.

(3) The speed of electromagnetic waves in vacuum (or air) is 3×10^8 ms^{-1}.

(4) Electromagnetic waves undergo reflection, refraction and diffraction.

(5) Electromagnetic waves can be polarised.

(6) Accelerated charged particles produce electromagnetic waves.

(7) c = speed of electromagnetic waves in vacuum is $\frac{1}{\sqrt{\mu_0 \epsilon_0}}$, where μ_0 and ϵ_0 denote permeability and permittivity of free space.

(8) The amplitude of electric and magnetic fields are related to one another as $B_o = E_o/c$.

(9) The energy in electromagnetic waves is equally divided between electric and magnetic fields. The average electric energy density = $(1/2) \epsilon_0 E_o^2$ and the average magnetic energy density = $\frac{1}{2\mu_o} B_o^2$

The Electromagnetic Spectrum

The electromagnetic spectrum has been divided into various parts and in order of increasing waves length. The following table gives electromagnetic spectrum.

Brief Account of different parts of Electromagnetic Spectrum

The *infrared rays* were discovered by Sir William Herschel in 1800, and are characterized by their heating effect.

Visible light is emitted by all incandescent bodies and ionized gases. The sensation of sight associated with it, is its unique characteristic.

Ultraviolet rays were studied first by Ritter in 1801, through their effect on photographic plates.

X-rays were discovered by Rontgen in 1895, and are produced whenever fast moving electrons are sudd stopped by a target. They can be diffracted by crystals and this led to the development of the subject of X-ray crystallography.

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γ-*rays* are emitted from nuclei of elements and were discovered by Henry Becquerel in 1896.

The discovery of radio waves is associated with Hertz's experiments in 1887. They have revolutionized communication. The use of microwaves, millimeter waves and artificial geostationary satellites now make it possible for us to transmit signals between practically any two points on the earth.

The atmosphere is transparent to visible light and the more energetic infrared rays.

The ozone layer in the bottom, *D* layer of the ionosphere and the top of the mesosphere protects the earth from the harmful ultraviolet rays present in sunlight.

S. No.	Name	Waves length range (m)	Frequency range (Hz)	Source
1.	γ-rays	6×10^{-14} to 10^{-11}	5×10^{22} ot 3×10^{19}	Nuclear reactions.
2.	X-rays	10^{-11} to 3×10^{-8}	3×10^{19} to 10^{16}	Sudden stoppage of high speed electrons
3.	Ultra-violet	6×10^{-10} to 4×10^{-7}	5×10^{17} to 8×10^{14}	Emission by excited atoms; arc lamp.
4.	Visible light	4×10^{-7} to 8×10^{-7}	8×10^{14} to 4×10^{13}	Emission by excited atoms fluorescent tube etc.
5.	Infra-red	8×10^{-6} to 3×10^{-5}	4×10^{14} to 10^{13}	Emission by excited atoms and molecules
6.	Thermal radiations	10^{-5} to 10^{-1}	3×10^{13} to 3×10^{9}	Hot bodies.
7.	Micro waves	10^{-3} to 0.3	3×10^{11} to 10^{9}	Special tube.
8.	Ultra high frequency	10^{-1} to 1	3×10^{9} to 3×10^{8}	Oscillating circuits.
9.	Very high frequencies	1 to 10	3×10^{8} to 3×10^{7}	Oscillating circuits.
10	Radio frequencies (R – F)	10 to 10^{4}	3×10^{7} to 3×10^{4}	Oscillating circuits.

Propagation of Radio Waves through the Atmosphere

The propagation of radio waves through the atmosphere takes place in three ways :

(i) The ground waves (ii) The sky waves and (iii) The space waves.

(i) Ground wave propagation is said to take place when the electromagnetic waves are actually guided by the earth and follow its curvature. We have directly propagating surface waves and ground reflected surface waves as the two types of ground waves.

(ii) When the energy radiated from a transmitter reaches the receiving end due to their bending and reflection by the atmospheric layers, we speak of 'sky wave' propagation. The ionosphere plays a crucial role in this type of wave propagation.

(iii) Space wave propagation takes place via two paths : the direct line of sight path and the ground reflected path. This mode of wave propagation is very important at high frequencies.

Let h be height of the transmitting antenna and d the distance up to which direct line of sight transmission reaches. d is known as range of antenna and $d = \sqrt{2Rh}$, where R is radius of earth.

The Basic Equations of Electromagnetism

Gauss's law in electrostatics, Faraday's law of electromagnetic induction and the non-existence of free poles are three of the four basic laws of electromagnetism.

Ampere's circuital law is the fourth basic law of electromagnetism. According to this law, the line integral of the magnetic field around any closed circuit is equal to μ_0 times of the total current threading the closed circuit, *i.e.*,

$$\oint \mathbf{B}\cdot d\boldsymbol{l} = \mu_0 I$$

Maxwell's modification of Ampere's Law: The Displacement Current

Maxwell showed that Ampere's law is as such valid only in the domain of magnetostatics. For non-steady currents, the modified form of Ampere's law is

$$\oint \mathbf{B}\cdot d\boldsymbol{l} = \mu_0 \cdot I + \mu_0 \in_0 \frac{d\phi_E}{dt} = \mu_0 (I + I_D)$$

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Here the second term, namely $I_D = \epsilon_0 \frac{d\phi_E}{dt}$ is known as the displacement current.

The Maxwell's Equations

The four basic equations of electromagnetism are :

(i) *Gauss's law of electrostatics:*

$$\int_s \mathbf{E}.d\mathbf{S} = \frac{1}{\epsilon_0} \cdot Q$$

(ii) *Faraday's law :*

$$\int \mathbf{E}.d\boldsymbol{l} = -\frac{d\phi B}{dt} = -\frac{d}{dt}\left[\int_S \mathbf{B} \,.\, d\mathbf{S}\right]$$

(iii) *Gauss's law of magnetostatics:*

$$\oint \mathbf{B} \cdot d\mathbf{S} = 0$$

According to Gauss's law of magnetostatics, isolated north or south pole does not exist.

(1) The *modified Ampere's law:*

$$\oint \mathbf{B}.d\boldsymbol{l} = \mu_0 I + \mu_0 \epsilon_0 \frac{d\phi_E}{dt}$$

Maxwell on the basis of above four equations showed that the electric and magnetic fields satisfy the wave equation. He showed that speed of elctromagnetic waves in vacuum is

$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$, where μ_0 and ϵ_0 denote the permeability and permittivity of free space.

The amplitude of electric field (E_0) oscillations and the magnetic field (B_0) oscillations are related to one another as

$$B_0 = \frac{E_0}{c}$$

The average energy density of the electromagnetic waves $= \frac{1}{2} \epsilon_0 E^2$.

SUBJECTIVE QUESTIONS ON UNIT – VII

Q.1. *What are electromagnetic waves?* **(1)**

Ans. The electromagnetic waves are those waves in which there are sinusoidal variation of electric and magnetic field vectors at right angles to each other as well as right angles to the direction of wave propagation.

Q.2. *Name the scientist, who predicted the existence of electromagnetic waves.* **(1)**

Ans. James Clark Maxwell.

Q.3. *What is the speed of electromagnetic waves in vacuum?* **(1)**

Ans. 3×10^8 ms^{-1}.

Q.4. *What is the medium if any, in which electromagnetic waves ordinarily travel?* **(1)**

Ans. Ordinarily electromagnetic waves do not require any medium for propagation. Electromagnetic waves can travel in vacuum.

Q.5. *Can electromagnetic waves be longitudinal?* **(1)**

Ans. No; electromagnetic waves are always transverse in nature.

Q.6. *For electromagnetic waves, write the relationship between amplitudes of electric & magnetic fields.* **[CBSE 1995] (1)**

Ans. Let E_0 and B_0 denote the amplitude of the electric and magnetic fields, then $B_0 = \frac{E_0}{c}$, where c is speed of light.

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Q.7. *Name the scientist, who first developed and operated the first transmitter and receiver of electromagnetic waves?*

Ans. Hertz; his experiments provided the requisite experimental support Maxwell's theory.

Q.8. *What are the essential properties of electromagnetic waves?*

Ans. The following are the main properties of electromagnetic waves :

(i) Electromagnetic waves are transverse in nature. The direction of vibration of **E** and **B** are mutually perpendicular and also perpendicular to direction of wave propagation.

(ii) Speed of electromagnetic waves in vacuum is 3×10^8 ms^{-1}.

(iii) Speed of electromagnetic waves in different media is different.

(iv) The variation of **E** and **B** are in phase.

(v) Speed of electromagnetic waves (c) in vacuum is $c = \frac{1}{\sqrt{\mu_0 \in_0}}$, where μ_0 and $\in_0$ denote the permeability and permittivity of free space.

(vi) Electromagnetic waves obey the laws of reflection and refraction.

(vii) Electromagnetic waves undergo interference and diffraction.

(viii) Electromagnetic waves can be polarised.

Q.9. *State four properties of electromagnetic waves.* **(CBSE, 1995)**

Ans. See question no. 8.

Q.10. *State the basic facts of Maxwell's theory of electromagnetic waves?*

Ans. According to Maxwell, an electromagnetic wave is constituted by oscillating electric and magnetic fields. The directions of the two fields are mutually perpendicular. The direction of wave propagation is at right angles to both the directions of oscillating electric and magnetic fields.

Q.11. *What were the four results that formed the basis of Maxwell's prediction of electromagnetic waves? Why was that prediction regarded as significant?*

Ans. The four basic results forming the basis of Maxwll's prediction of electromagnetic waves are:

(i) Gauss's law of electrostatics

(ii) Gauss's law of magnetostatics

(iii) Ampere's circuital law

(iv) Faraday's laws of electromagnetic induction.

The prediction was significant because it showed that light is nothing but varying electric and magnetic fields.

Q.12. *Draw a labelled diagram of Hertz's experiment for producing electromagnetic waves.*

Ans. A and B are two large metal spheres. S_1 and S_2 are highly polished metallic spheres. Induction coil applies high potential difference (of order of several thousand volts) across S_1 & S_2.

Fig (b) shows Hertz's receiver. It consists of a closed metallic ring having small metallic spheres C and D.

Q.13. *Describe the Hertz's experiments to produce eletromagnetic waves. Comment on the importance of those experiments.*

Ans. Fig. above shows Hertz's transmitter and receiver. The high voltage applied across S_1 and S_2 causes a spark to pass between them. This is the transmitted signal. The sphere S_1 and S_2 act as a capacitor. The connecting wires provide a low value inductance. The frequency (f) of oscillations produced is

$$f = \frac{1}{2\pi\sqrt{LC}}$$

In Hertz's experiment f is of the order of 10^6 Hz.

In the receiver the gap between C and D is so adjusted that its natural frequency is same as that of transmitter. The oscillating electric and magnetic field of transmitter produce resonant oscillations in transmitter. This produces a large induced electromagnetic f and, therefore, a spark to appear in between C and D.

Q.14. *Give a brief account of Bose's experiment on electromagnetic waves.*

Ans. Bose's experiment on electromagnetics waves

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(i) Providing experimental support to Maxwell's electromagnetic theory of radiation.

(ii) Showed that waves, that cannot be seen, can be transmitted through space and received at a distance; without there being any connection between transmitter and receiver via wires.

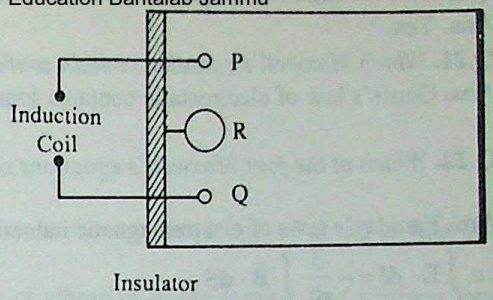

Fig. above shows the oscillator used by Bose. P, Q and R are spheres made of platinum. Spheres P and Q are connected to induction coil. Sphere R is mounted on an insulator. When induction coil is switched on, a spark jumps between spheres P and R as well as between Q and R. This is the production of electromagnetic waves. The cylindrical lens focuses electromagnetic waves produced on an appropriate detector. In Bose's experiment, the detector was a movable brass contact. When electromagnetic waves fall on it, the resistance of spiralled detector decreased. The decrease shows an increase in current through a sensitive galvanometer connected across the Bose detector. The wavelength of waves produced in Bose's experiment lies in between 5 mm to 25 mm. Bose's experiment showed that

(i) electromagnetic waves are similar to "visible light", and (ii) electromagnetic waves can be used for wireless telegraphy.

Q.15. *Do all current carrying conductors emit electromagnetic waves? Explain.* **(2)**

Ans. No. If a conductor carriers direct current (d.c.) there is no variation of electric flux (ϕ_E). The displacement current $I_d = \epsilon_0 \frac{d\phi_E}{dt}$ is, therefore, zero. However, if current flowing in conductor is alternating (a.c); $\frac{d\phi_E}{dt}$ is finite. There is displacement current and electromagnetic waves are produced.

Q.16. *Give an account of Marconi's experiment.* **(2)**

Ans. Marconi, in 1901, set up a transmitter and a receiver across the Atlantic. The letter *S* was transmitted in morse code and received across the Atlantic covering a distance of 2900 km without any wire contact between transmitter and receiver. Wireless telegraphy had become a practical reality.

Q.17. *Comment on the significance of Marconi's experiments in the development of "wireless telegraphy"* **(2)**

Ans. Marconi's experiment showed that signals could be transmitted from one place to another without any wire contact between transmitted and receiver. Marconi's experiment is a landmark in the history of radio telegraphy. **(CBSE 1990) (2)**

Q.18. *Discuss green house effect.*

Ans. The heating of earth's atmosphere due to trapping of infrared rays (radiated from the surface of earth), by the carbon dioxide layer in the atmosphere is known as the *"greenhouse effect"*.

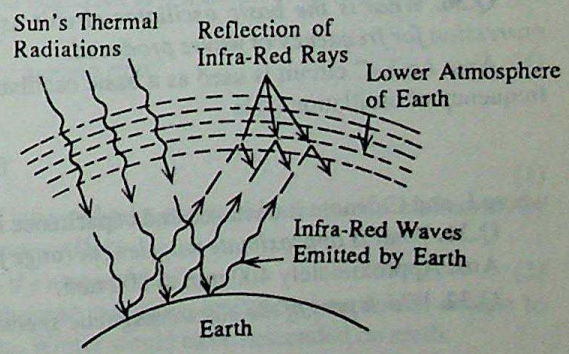

Fig. above shows heat (thermal) radiations from the Sun, reaching earth after passing through the atmosphere of earth. These rays heat the earth. The hot surface of earth itself starts emitting infrared rays. These infrared rays are reflected back towards earth by gases in the lower atmosphere of earth. The clouds also prevent the infra-red radiations emitted by earth to escape into space above earth's atmosphere. The earth's atmosphere in richer is thermal radiations and keeps earth warm. Had the infrared radiations emitted by earth escaped into space, the surface termperature of earth would fall or a winter would descend on earth.

Q.19. *Are the Maxwell's equations true for different types of media such as dielectrics and conductors?* **(1)**

Ans. Maxwell's equations are true for all media.

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Q.20. *Are the Maxwell's equations true for arbitrary high and low values of* **E** *and* **B***?*

Ans. Yes.

Q.21. *Which Maxwell's equation contain source of* **E** *and* **B***?* (1)

Ans. Gauss's law of electrostatic contains source of **E** and modified Ampere's circuital law contains source of **B.**

Q.22. *Which of the four Maxwell's equations show that electrostatic field lines cannot form closed loops?* (1)

Ans. Faraday's laws of electromagnetic induction.

$$i.e, \int \mathbf{E} \cdot \mathbf{dl} = -\frac{d}{dt} \int \mathbf{B} \cdot \mathbf{dS}$$

Q.23. *Which of the four Maxwell's equation shows that magnetic field lines neither start from a point nor end at a point?* (1)

Ans. Gauss's law of magnetostatics, *i.e.,*

$$\oint \mathbf{B} \cdot \mathbf{dS} = 0$$

Q.24. *Which of the four equations of electromagnetism was used by Maxwell after modifying it?* (1)

Ans. Ampere's circuital law.

Q.25. *What is meant by displacement current?* (1)

Ans. The displacement current is a current, produced by a varying electric flux.

Q.26. *What expression for displacement current was suggested by Maxwell?* (1)

Ans. Expressed mathematically, $I_d = \epsilon_0 \frac{d\phi_E}{dt}$

Q.27. *A capacitor is connected to an a.c. Is the conduction in connecting wires, equals the displacement current in the capacitor?* (1)

Ans. Yes.

Q.28. *How does the idea of displacement current help us to associate 'symmetry' in the behaviour of electric and magnetic fields?* (2)

Ans. According to Faraday's law of electromagnetic induction, a varying magnetic flux produces an induced e.m.f. According to Maxwell, a varying electric flux should also produce a current and, therefore, a magnetic field. This current is displacement current. Since variation in flux due to electric field produces a magnetic field and vice-versa, the behaviour of electric and magnetic fields is symmetrical.

Q.29. *Once a capacitor has been fully charged using d.c. source, what are the magnitudes of the "conduction" current and the "displacement current"?* (1)

Ans. The conduction and displacement currents are both zero after the capacitor has got fully charged.

Q.30. *What is the basic oscillator circuit used now a days to produce electromagnetic waves? Give an expression for frequency of waves produced.* (1)

Ans. An L-C circuit is used as a basic oscillator circuit to produce electromagnetic waves, now a days. The frequency of oscillation (f) is

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where L and C denote inductance and capacitance in L-C circuit.

Q.31. *What is approximate wavelength range for visible spectrum?* (1)

Ans. Approximately 400 mm to 800 mm.

Q.32. *Which part of the electromagnetic spectrum does the wavelength of 10^{-10} m correspond to?* (1)

Ans. X-rays

Q.33. *Which one of (i) the radio waves and (ii) visible light has longer wavelength?* (1)

Ans. Radio waves.

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Q.34. *Who discovered infrared rays?*
Ans. Sir William Herschel. **(1)**

Q.35. *Name one important characteristic of infrared rays.*
Ans. Heating effect. **(1)**

Q.36. *Who discovered ultraviolet rays?*
Ans. Ritter in 1801. **(1)**

Q.37. *What are micro waves?* **(1)**
Ans. Microwaves are the part of electromagnetic spectrum having frequency of about a few hundred megahertz and wavelength of a few mm.

Q.38. *What is the order of magnitude of the frequency of vibration of the longest and shortest waves in electromagnetic spectrum?* **(1)**
Ans. The frequency of vibration of longest waves is of the order of 10^5 Hz. The frequency of vibration of shortest waves is of the order of $10^{20} - 10^{25}$ Hz.

Q.39. *Name the different constituents of the complete electromagnetic spectrum and comment briefly on the salient characterstics of each.* **(3)**
Ans. The following table gives the constituents of the complete electromagnetic spectrum and their respective salient characterstics.

S. No.	Name of constituents	Salient characteristics
1.	The infra-red light	Heating effect
2.	The visible light	Causes sensation of vision.
3.	Ultra-violet rays	Invisible rays. Can cause fluorescence and phosphorescence.
4.	X-rays	Ability to produce shadow pictures of bones on photographic plates.
5.	γ-rays	Originate from the nucleus of the source atom.
6.	Radio waves and microwaves	Because of their high frequency, can travel as a "beam" in a particular direction.

Q.40. *What is the order of the wavelength and frequency of X-rays?* **(1)**
Ans. The wave length of X-rays varies from a few hundred angstrom to a fraction of an angstrom ($\approx$ 400 Å to 0.1 Å). The frequency lies in the interval $10^{16} - 3 \times 10^{19}$ Hz.

Q.41. *What is the order of the wavelength and frequency of gamma rays?* **(1)**
Ans. Wave length range a few 10^{-11} to 6×10^{-14} m
Frequency range 3×10^{19} to 5×10^{22} Hz.

Q.42. *What is "the green house effect"?* **(1)**
Ans. The heating of earth's atmosphere due to trapping of infra-red rays, radiated by hot surface of earth, by the carbon dioxide layer in atmosphere is known as the green house effect.

Q.43. *Discuss the significance of the green house effect in the atmosphere?* **(2)**
Ans. Had the green house effect been non existent, the thermal radiations emitted by earth will escape to outer space. The surface temperature of earth would have fallen. Winter would have descended on earth.

Q.44. *The ozone layer in the atmosphere is crucial for human survival. Why?*
CBSE 1995 Comptt.] (2)
Ans. The small ozone layer present on top of the stratosphere absorbs (i) Ultraviolet radiations (ii) X-rays (iii) γ-rays from the sun and (iv) cosmic - rays.

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These rays are harmful causing even genetic changes in living cells. Since ozone layer prevents these harmful rays from reaching earth's surface, (ozone layer) is essential for the survival of life on earth.

Q.45. *Name the electromagnetic radiations used for viewing objects through haze and fog.*

(CBSE 1997) (1

Ans. Infrared radiations.

Q.46. *What is the range of frequencies used for T.V. transmission?* **(CBSE 1997 Comptt.)** (1

Ans. 100 MHz to 200 MHz.

Q.47. *Why do long distance radio broadcasts used shortwave bands?* **(CBSE 1997 Comptt.)** (1

Ans. Because ionosphere reflects the waves in this band.

Q.48. *Name the different layers of earth's atmosphere. How does earth's atmosphere help in the propagation of radiowaves?* **(CBSE 1996 Comptt.)** (2

Ans. (i) Troposphere (ii) Stratosphere (iii) Mesosphere (iv) Ionosphere.

Radiowaves and microwaves (waves whose wavelength is longer than 1 mm) are relevant as far as transmission and communication are concerned. The earliest experiments of Hertz and Marconi, on radio-communication, used waves of wavelengths 10 m or more. The lower atmosphere is transparent to waves of these wavelengths but the upper atmospheric layer called the ionosphere reflects them back to earth. This property is, therefore, made to use of in radio-communication.

Q.49. *Write the frequency limit of visible range of electromagnetic spectrum in kHz.*

(CBSE 1998) (1

Ans. 3.9×10^{11} kHz to 7.5×10^{11} kHz.

Q.50. *Write the following radiations in an ascending order in respect of their frequencies:*

X-rays, microwaves, ultraviolet rays, radiowaves. **(CBSE 1998)** (1

Ans. Radiowaves, microwaves, ultraviolet rays, X-rays.

Q.51. *Explain surface wave and sky wave propagations of radiowaves. Why is short wave communication over long distances not possible by surface wave propagation?* **(CBSE 1997)** (3

Ans. Surface wave propagation : The a.m. radiowaves, which are travelling directly following the surface of the earth are known as ground waves, or surface waves and this type of propagation is called ground wave propagation or surface wave propagation. Surface waves can have frequencies up to 1500 kHz.

Sky wave propagation : The a.m. radiowaves which are received after being reflected from the ionosphere are called as sky waves. and this type of propagation is called sky wave propagation. For the radio communication of the frequencies more than 1500 kHz, sky waves can only be used.

Short wave communication over long distances is not possible by ground wave propagation because their intensity falls with distance.

Q.52. *Name the electromagnetic radiations used for studying crystal structure of solids.* **(CBSE 1998)** (1

Ans. X-rays.

Q.53. *Which part of the elecromagnetic spectrum has highest frequency?* **(CBSE 1999)** (1

Ans. γ-rays.

Q.54. *Why are microwaves used in RADAR?* **(CBSE 1999)** (1

Ans. Because microwaves have greater energy and least angular spread.

Q.55. *Why is the transmission of signals using ground waves restricted to frequencies up to 1500 kHz?*

(CBSE 1999, 2000) (1

Ans. The ground wave propagation becomes weaker as frequency increases because higher frequency waves are rapidly damped due to their interaction with matter. Hence, it is restricted to waves to frequencies below 1500 kHz.

Q.56. *Which part of the electromagnetic spectrum has largest penetrating power?*

(CBSE 1999) (1

Ans. γ-rays.

Q.57. *Derive an expression for maximum range up to which signals transmitted by a T.V. tower can reach.*

(CBSE 1999) (3

Ans. See answer to question no. 64.

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Q.58. *Give a reason to show that microwaves are better carriers of signals for long range transmission than radiowaves.* **(CBSE 2000) (1)**

Ans. Microwaves have smaller wavelengths, thus, can be transmitted as beam signals in a particular direction much better than radiowaves. It is because radiowaves do not bend around the corners of any obstacle in their path.

Q.59. *State the principle of RADAR. Derie the expression for the range up to which T.V. signals transmitted by a T.V. tower can reach.* **(CBSE 2000) (3)**

Ans. In a RADAR, microwaves are sent from a transmitter towards a distant object and the reflected waves are picked up by a receiver. If the waves are received back in time t, then the distance of the distant object is $D = \frac{ct}{2}$, where c is the speed of light.

See answer to question no 64 for IInd part.

Q.60. *It has been predicted that a global nuclear war on the earth would be followed by a severe 'winter'. What could be the basis of this prediction?* **(2)**

Ans. The clouds due to global nuclear war would perhaps cover most of the sky. This will prevent visible light and thermal radiations from the sun reaching the earth. The absence of thermal radiation on earth will cause a decrease in its surface temperature resulting in a "*winter*".

Q.61. *Why are not sky waves used for the transmission of T.V. signals? Name two methods by which range of T.V. transmission can be increased.* **[CBSE 1995 comptt.] (2)**

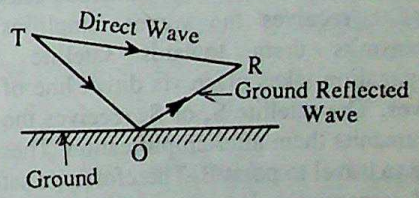
Ans. The waves used in T-V transmission (*i.e.*, the microwaves) do not undergo total internal reflection in the ionosphere.

The range of T.V. transmission can be increased by using :

(i) more powerful transmitter and (ii) increasing the height of transmission antenna.

Q.62. *What is the role of space wave propagation in the transmission of high frequency signals?* **(2)**

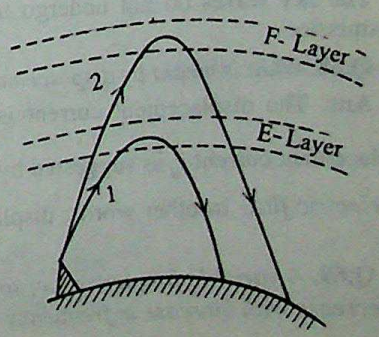
Ans. If frequency of waves to be transmitted exceeds 30 MHz, they cannot be transmitted by (i) ground waves or (ii) sky waves. For frequencies exceeding 30 MHz, the propagation is by means of space waves. The space waves travel directly between a high transmitting antenna and receiving antenna. Fig. below shows a high altitude transmitter antenna T and a receiver antenna R. Waves reach R by two ways :



(i) The direct line of sight path TR; and (ii) the ground reflected path TOR. At high frequencies the direct waves become increasingly important and are used for T.V. signal transmission. Microwaves, because of their higher frequency, travel along the direct line of sight much better than radiowaves. This is the reason microwaves are increasingly being used in wireless communication.

Q.63. *Long distance radio broadcasts use short wave bands. Why?* **(2)**

Ans. Long distance radio communication is via sky waves. The sky waves can reach points at a long distance from the transmitter. This is due to reflection by various layer's of *ionosphere*. The refractive index of different layers of atmosphere is different for electromagnetic waves. This variation is due to differences in the degree of ionisation of different layers. In ionosphere the higher layers have a smaller refractive index than layers at a lower level. The electromagnetic waves pass from a denser to a rarer medium and undergo total internal reflection as shown below. The frequency of waves decide the layer where total internal reflection takes place. In Fig. 5, waves 1 have a smaller frequency (i.e., longer wavelength) and are totally reflected from E-layer. However, waves 2 have a higher frequency or shorter wavelength and are totally reflected from F-layer. Clearly short wavelength waves travel a longer distance.



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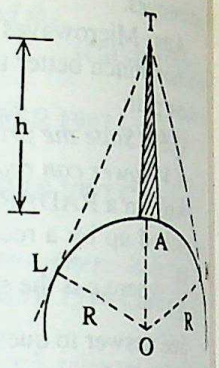
Q.64. *How does an increase in the height of a T.V. transmission antenna help in increasing its "coverage range"?*

Ans. Fig. below shows a transmission antenna T at height AT = h above the surface of earth at point A. From T draw TM and TL as tangent to earth. The waves can reach earth within points L and M. Let R be radius of earth (assumed to be a sphere). From rt. angled Δ OMT



$$OT^2 = TM^2 + OM^2$$

or $(R + h)^2 = TM^2 + R^2$

or $TM = (h^2 + 2Rh)^{1/2}$

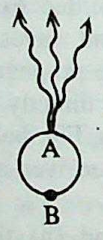
Usually R >> h; so that TM = AM = d, the distance up to which the waves from the antenna can reach earth. This is a measure of the *"coverage range"*. Obviously, d increases with an increase in h. In other words, a tall antenna increases the range of coverage of T.V. signals.

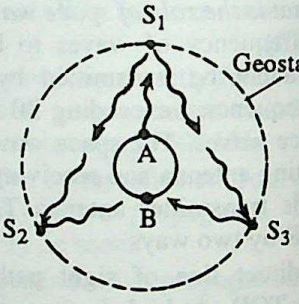
Q.65. *Optical and radio telescopes are built on the ground but X-ray astronamy is possible only from satellites orbiting the earth. Why?* (2)

Ans. Optical and radio frequency electromagnetic waves are able to pass through the atmosphere of earth. These waves reach earth. Therefore, ground telescopes are optical and radio telescope. On the other hand X-rays starting from an astronomical object are absorbed in the atmosphere around earth and cannot reach the earth. However a satellite moving above earth's atmosphere can receive these X-rays and, therefore, X-ray astronomy is only possible from satellites around earth and not from the surface of earth.

Q.66. *Is it necessary to use satellites for long distance T.V. transmission. Why?* (2)

Ans. Fig (a) below shows a transmitter at point A. The ground, sky waves cannot reach diametrically opposite, point B on earth. Fig. (b) shows three geostationary satellites S_1, S_2 and S_3. The T.V. signal from point A is transmitted towards satellite S_1. The satellite receives the waves, amplifies them and retransmits them towards satellite S_2 or S_3. Propagation takes place via direct line of sight space waves. The satellite S_2 or S_3 receives the waves, and retransmits them after amplification. These waves are able to travel to point B. Therefore, via satellite global T.V. transmission becomes possible.





Q.67. *Why are the ground wave and sky wave propagation methods not suitable for transmission of microwaves?* (2)

Ans. When microwaves are used for transmission, the ground waves are highly *attenuated* and, therefore, not useful for transmission.

The sky waves do not undergo total internal reflection in ionosphere and, therefore, are not useful for transmission.

Q.68. *What is meant by displacement current? Give Maxwell's expression for displacement current.* (2)

Ans. The displacement current is the current produced by a varying electric field. The expression for displacement current i_d as suggested by Maxwell is $I_d = \epsilon_0 \frac{d\phi_E}{dt}$, where ϵ_0 is permittivity of free space and ϕ_E is the *electric flux*. In other words, displacement current is directly proportional to the rate of charge of electric flux.

Q.69. *A variable frequency a.c. source is connected to a capacitor. Will the displacement current increase or decrease with increase in frequency of source?* (3)

Ans. The displacement current $I_d = \epsilon_0 \frac{d\phi_E}{dt}$.

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Let $f = f_0 \sin \omega t$ be the variable frequency a.c. source connected to capacitor of capacity C. The instantaneous charge q on capacitor is $q = Cf = C f_0 \sin \omega t$. The electric flux $\phi_E = \frac{q}{\epsilon_0}$

$$\therefore \quad \frac{d\phi_E}{dt} = \frac{d}{dt}\left(\frac{Cf_0}{\epsilon_0} \sin \omega t\right) = \frac{Cf_0}{\epsilon_0} \omega \cos \omega t$$

$$I_d = \epsilon_0 \frac{d\phi_E}{dt} = Cf_0 \omega \cos \omega t$$

Obviously, I_d increases as the frequency ω of applied a.c. increases.

Q.70. *Give Maxwell's equations.* **(3)**

Ans. The four Maxwell's equations are :

(i) $\oint \mathbf{E}.\mathbf{ds} = \frac{q}{\epsilon_0}$

(ii) $\oint \mathbf{E}.\mathbf{dl} = -\frac{d\phi_B}{dt} = -\frac{d}{dt}\oint_s \mathbf{B}.\mathbf{ds}$

(iii) $\oint \mathbf{B}.\mathbf{ds} = 0$

(iv) $\oint \mathbf{B}.\mathbf{dl} = \mu_0 I + \mu_0 \epsilon_0 \frac{\partial \phi_E}{\partial t}$

SOLVED NUMERICAL PROBLEMS ON UNIT – VII

Example 1. *In a plane electromagnetic wave the electric field oscillates sinusoidally with a frequency of* 20×10^{10} *Hz and amplitude 48* Vm^{-1}. *What is the wave length of the wave ?* **(CBSE, 1990)**

Solution : $f = 20 \times 10^{10}$ Hz; $c = 3 \times 10^8$ ms^{-1}

$$\therefore \quad \lambda = c/f = \frac{3 \times 10^8}{2 \times 10^{11}} = \mathbf{1.5 \times 10^{-3}\ m}.$$

Example 2. *The electric field vector of a plane electromagnetic wave oscillates sinusoidally at a frequency of* 4.5×10^{10}*Hz. What is the wavelength?*

Solution : $f = 4.5 \times 10^{10}$ Hz; $c = 3 \times 10^8$ ms^{-1}. Also $c = f\lambda$

$\therefore \lambda = c/f = 3 \times 10^8/4.5 \times 10^{10}$ m $= \mathbf{0.667 \times 10^{-2} m}$.

Example 3. *In a plane electromagnetic wave the electric field oscillates with a frequency of* 2×10^{10} sec^{-1} *and an amplitude of 40* Vm^{-1}.

(i) What is the wavelength of the wave?

(ii) What is energy density due to the electric field? **(CBSE 1997 Comptt.)**

Solution: Here, $f = 2 \times 10^{10}$ sec^{-1}, $E_0 = 40$ Vm^{-1}, $c = 3 \times 10^8$ m/sec.

(i) $\lambda = \frac{c}{f} = \frac{3 \times 10^8}{2 \times 10^{10}} = \mathbf{1.5 \times 10^{-2}\ m}$

(ii) Energy density $= \frac{1}{2}\epsilon_0 (E_0)^2 = \frac{1}{2} \times 8.85 \times 10^{-12} \times 40 \times 40 = \mathbf{7.08 \times 10^{-9}\ Jm^{-3}}$.

Example 4. *We are given the following facts about a plane electromagnetic wave :*

Oscillation frequency of the electric field $= 3.0 \times 10^{14}$ *Hz.*

Amplitude of the oscillating electric field = $60\ Vm^{-1}$

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Determine the wavelength of the electromagnetic wave and identify the region of electromagnetic spectrum to which it belongs. What is the amplitude of the magnetic field oscillations?

Solution : The wavelength $\lambda = c/f$. Given

$f = 3 \times 10^{14}$ Hz and $c = 3 \times 10^{8}$ ms^{-1}. Therefore,

$\lambda = 3 \times 10^{8}/3 \times 10^{14}$ m $= 10^{-6}$ m $= 10^{4}$ Å

The wave lies in the infra-red region of electromagnetic spectrum.

Let E_0 and B_0 denote the amplitude of the electric and magnetic oscillations.

$B_0 = E_0/c$. Given $E_0 = 60$ Vm^{-1}, therefore,

$B_0 = 60 / (3 \times 10^{8}) = \mathbf{2 \times 10^{-7}}$ **T.**

Example 5. *A T.V. tower has a height of 100 m. How much population is covered by the T.V. broadcast, if the average population density around the tower is 1000 km^{-2}. Radius of earth = 6.37×10^{6} m* **(CBSE., 1991)**

Solution : Let d be the distance of farthest point from tower where the T.V. coverage takes place.

$d = \sqrt{h^2 + 2hR}$.

Given h = 100 m; $R = 6.37 \times 10^{6}$ m

$\therefore d = \sqrt{(100)^2 + 2 \times 100 \times 6.37 \times 10^{6}}$

$= \sqrt{12.74 \times 10^{8}} = 3.5693 \times 10^{4}$ m $= 35.693$ km

The population covered by T.V. broadcast lies within a circle of radius 35.693 km with tower as centre. Therefore, population covered by T.V. transmission = $\pi d^2 \times$ density of population.

$= 3.142 \times (35.693 \text{ km})^2 \times (1000)\ (\text{km})^{-2}$

$= 4.00028 \times 10^{6} = \mathbf{4 \times 10^{6}}$.

Example 6. *A T.V. transmission tower has a height of 160 m.*

(a) *What is the coverage range? (b) If average density around tower is 1500 km^{-2}, what is population covered? (c) By what factor should height of tower be altered so that the coverage range is doubled? Given radius of earth = 6400 km.*

Solution : The coverage range (d) of a transmission tower of height (h) is $d = \sqrt{2Rh}$, where R is radius of earth. Given h = 160m; R = 6400 km $= 6.4 \times 10^{6}$ m **[Since h << R, we have** $d = \sqrt{2hR}$**]**

$\therefore \quad d = \sqrt{2 \times 160 \times 6.4 \times 10^{6}}$ m

$= 45.254 \times 10^{3}$ m $=$ **45.254 km**

(b) The area covered by transmission tower

$= \pi(d)^2 = 3.142 \times (45.254)^2$ km^2

The population covered = population density × area covered by transmission

$= 1500 \times 3.142 \times (45{\cdot}254)^2$

$= 9651868 \approx \mathbf{9.65 \times 10^{6}}$

(c) Let H′ be height of tower so that coverage range is doubled. Then

$2 \times 45.254 \times 10^{3} = \sqrt{2 \times 6.4 \times 10^{6} \times H'}$

or $\quad H' = \dfrac{(2 \times 45.254)^2 \times 10^{6}}{2 \times 6.4 \times 10^{6}}$ m $= 639.9$ m

$\dfrac{H'}{H} = \dfrac{639.9}{160} \approx \mathbf{4.}$

Example 7. *A parallel plate air capacitor has a capacity of 2 pF. The electric field in between plates varies at a rate of 10^{12} Vm^{-1} s^{-1}. What is displacement current?*

Solution : The displacement current (I_d) in a capacitor is

$$I_d = C \frac{dV}{dt}$$

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Given $C = 2pF = 2 \times 10^{-12}$ F; $\frac{dV}{dt} = 10^{12}$ $Vm^{-1}s^{-1}$

$\therefore I_d = 2 \times 10^{-12} \times 10^{12}$ A = **2 A.**

Example 8. *How a displacement current of 1A, can be established in the space between the two plates of a parallel plate capacitor of capacity 1μF?*

Solution : Let $\frac{dV}{dt}$ be the rate of change of electric potential in between the plates of parallel plate capacitor.

The displacement current (I_d) is $I_d = C \frac{dV}{dt}$

Given

$I_d = 1A$; $C = 1\mu F = 10^{-6}$ F

$\therefore \quad 1 = 10^{-6} \frac{dV}{dt}$ or $\frac{dV}{dt} = \mathbf{10^6}$ $\mathbf{Vs^{-1}}$

Example 9. *In a plane electromagnetic wave, the electric field oscillates sinusoidally at a frequency of 2×10^{10} Hz and amplitude 48 Vm^{-1}. (a) What is the wavelength of the wave? (b) What is the amplitude of the oscillating magnetic field? (c) Find the total average energy density of the electromagnetic field of the wave.*

(CBSE 1990)

Solution : Given

$f = 2 \times 10^{10}$ Hz; $E_0 = 48$ Vm^{-1} and $c = 3 \times 10^8$ ms^{-1}

(a) $\lambda = \frac{c}{f} = \frac{3 \times 10^8}{2 \times 10^{10}} = \mathbf{1.5 \times 10^{-2}}$ **m**

(b) B_0 = the amplitude of oscillating magnetic field $= \frac{E_0}{c} = \frac{48}{3 \times 10^8} = \mathbf{1.6 \times 10^{-7}}$ **T**

(c) Total average energy density $= \frac{1}{2} \in_0 E_0^2$

$$= \frac{1}{2} \times 8.85 \times 10^{-12} \times (48)^2 \text{ Jm}^{-3}$$

$$= \mathbf{1 \times 10^{-8}} \text{ Jm}^{-3}.$$

Example 10. *A millimeter wave has a wavelength of 2.0 mm and the oscillating electric field associated has an amplitude of 20 Vm^{-1}. Determine the frequency of oscillations of the electric and magnetic fields. What is amplitude of magnetic field oscillations?*

Solution : Given $\lambda = 2mm = 2 \times 10^{-3}$ m; $c = 3 \times 10^8$ ms^{-1}; $E_0 = 20$ Vm^{-1}

$\therefore \quad f = \frac{c}{\lambda} = \frac{3 \times 10^8}{2 \times 10^{-3}} = \mathbf{1.5 \times 10^{11}}$ Hz

B_0 = amplitude of oscillation of magnetic field $= \frac{E_0}{c} = \frac{20}{3 \times 10^8}$ T $= \mathbf{0.667 \times 10^{-7}}$ **T.**

Example 11. *The magnetic field in an electromagnetic wave oscillates with an amplitude of 2×10^{-7} T. What would be the amplitude of the electric field, if the wave is travelling in water of refractive index $\frac{4}{3}$?*

Solution : Let v be speed of electromagnetic waves in water of $\mu = \frac{4}{3}$. By definition $\mu = \frac{c}{v}$

$$v = \frac{c}{\mu} = \frac{3 \times 10^8}{\left(\frac{4}{3}\right)} = 2.25 \times 10^8 \text{ ms}^{-1}$$

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Let E_0 and B_0 be the amplitude of the electric and magnetic fields. Then

$E_0 = B_0 v$. Given $B_0 = 2 \times 10^{-7}$ T

$\therefore \quad E_0 = 2 \times 10^{-7} \times 2.25 \times 10^8 = \mathbf{45\ V}$.

Example 12. *A 100 watt incandescent lamp radiates all its energy in sinusoidal electromagnetic wave and that energy is emitted uniformly in all directions. Calculate maximum electric and magnetic intensities at a distance of 2m from the lamp.*

Solution : The energy radiated by bulb is distributed equally over an area of $4\pi(2)^2\ m^2 = 16\pi m^2$. The energy density $= 100/16\pi = 25/4\pi\ \text{Wm}^{-2}$. In electromagnetic waves on the average half of the energy is associated with **E** and the other half with **B.**

Therefore, V_E = energy density due to $\mathbf{E} = \frac{1}{2}\left(\frac{25}{4\pi}\right) \text{Wm}^{-2}$. Also, $U_E = \frac{1}{2} \in_0 E^2$.

Therefore, $\quad \frac{25}{2 \times 4\pi} = \frac{1}{2} \in_0 E^2$

or $\quad \frac{25}{2 \times 4\pi} = \frac{E^2}{2 \times 4\pi \times 9 \times 10^9}$

or $\quad E^2 = 25 \times 9 \times 10^9$

$\therefore \quad \mathbf{E \approx 47.5 \times 10^4\ Vm^{-1}}$

Similarly, the energy density of magnetic field

$$V_B = \frac{1}{2\mu_0} B^2$$

$\therefore \quad \frac{25}{2 \times 4\pi} = \frac{B^2}{2 \times 4\pi \times 10^{-7}}$

or $\quad B^2 = 25 \times 10^{-7}$

$\therefore \quad \mathbf{B \approx 1.6 \times 10^{-3}\ T}$.

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UNIT - VIII

WAVE OPTICS

CBSE SYLLABUS CONTENTS

Wavefront and Huygen's principle. Reflection and refraction of plane wave at a plane surface. Interference — Young's double slit experiment. Diffraction – diffraction due to a single slit. Linearly polarised light use of polarised light, use of polaroids. Doppler effect.

No. of periods allotted : 10 out of 168.

No. of marks allotted : 7 out of 70.

BASIC FACTS AND FORMULAE

1. According to Huygen, light has a wave nature. In a homogeneous isotropic medium, speed of waves is same at all points and in all directions. However, speed of waves is different in different media.

2. The wavefront at any moment of time is the locus of all the points of medium that are in same phase. The direction of ray is the direction of normal to the wavefront. For a point source, the wavefront is spherical. A plane wavefront corresponds to a parallel beam of light.

3. According to Huygen's principle of secondary wavelets, every point on the given wavefront is regarded as a hypothetical source of secondary wavelets. The new wavefront is the *tangential plane* (or *envelope)* of all secondary wavelets.

4. When two or more than two, identical sources are present simultaneously in a medium, there is redistribution of energy in medium. This is *interference* of light. At a point where disturbance from two sources arrive in phase, the resultant disturbance is more than due to either source. This is *constructive interference.* The condition for constructive interference is

$\Delta = n\lambda$ or $\delta = 2n, \pi$ where $n = 0, 1, 2, 3. ...$

Here Δ and δ denote the total path difference and phase difference respectively, between the two disturbances at a point on screen.

At a point on screen where the two disturbances arrive *out of phase* the two disturbances subtract. The resultant disturbance is less. This is *destructive interference.* The condition for destructive interference is

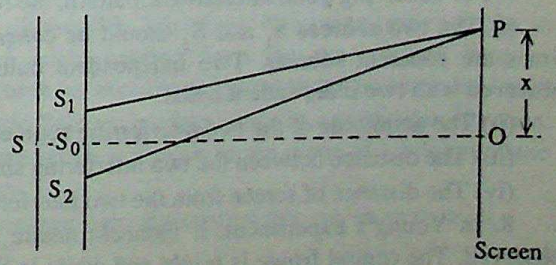
$$\Delta = (2n-1)\frac{\lambda}{2} \quad \text{or} \quad \delta = (2n-1)\pi \quad \text{where } n = 1, 2, 3, ...$$

5. In Young's double slit experement, S_1 and S_2 are two slits placed symmetrically with respect to a slit S illuminated with monochromatic light (Fig. below)

The interference pattern is observed on a screen at a large distance from S_1 and S_2. The central fringe O is bright. The path difference Δ, between the two disturbances at any point P on the screen is

$$\Delta = \frac{xd}{D}$$

The distance x_n of nth bright fringe from the central fringe is given by



$S_1S_2 = d \quad S_oO = D$

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$$\Delta = \frac{x_n d}{D} = n\lambda \quad \text{or} \quad x_n = \frac{n\lambda D}{d}$$

The distance between any two consecutive bright fringes is known as the frinage width (β) and

$$\beta = x_{n+1} - x_n = \frac{\lambda D}{d}$$

Similarly, the distance x_n' of the nth dark fringe from the central bright fringe is

$$\Delta = \frac{x_n' d}{D} = (2n-1)\ \frac{\lambda}{2}$$

or

$$x_n' = (2n-1)\ \frac{\lambda D}{2d}$$

The distance between any two consecutive dark fringes also equals β.

6. The intensity I at any point P on the screen, where the two disturbances arrive having phase difference is

$$I = I_{max} \cos^2 (\delta/2)$$

$I_{max} = \Delta I_0$, where I_0 is intensity of either interfering source.

In general, if a_1 and I_1 denote the amplitude and intensity of S_1 and a_2, I_2 denote corresponding quantities for S_2, the resultant amplitude (a) and intensity (I_1) at a point where the two disturbances arrive having a phase difference δ is

$$a^2 = a_1^2 + a_2^2 + 2a_1a_2 \cos\delta$$

and $$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\ \cos\delta$$

In general, if I_{max} and I_{min} denote intensity at a point of constructive and destructive interference respectively, then

$$\frac{I_{max}}{I_{min}} = \left(\frac{a_1 + a_2}{a_1 \sim a_2}\right)^2$$

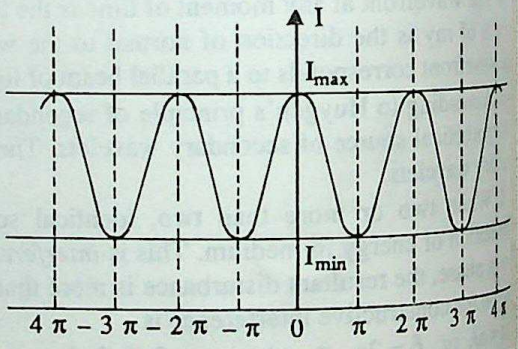

Fig. alongside shows variation of intensity on screen.

In interference, there is no violation of the law of conservation of energy. There is only a redistribution of energy. In Young's experiment, if I_0 is the intensity of either interfering source $I_{max} = 4I_0$. This is twice energy available due to both sources. However, there is no violation of law of conservation of energy. In Young's experiment $I_{min} = 0$. The average energy over one maxima and minima:

$$= \frac{I_{max} + I_{min}}{2} = \frac{4I_0 + 0}{2} = 2I_0$$

Therefore, there is only redistribution of energy.

7. For observing good interference pattern, the following Conditions should be satisfied.

(i) The two sources S_1 and S_2 should be ***coherent.*** Any two sources having same phase difference at all times are coherent sources. Two independent bulbs are not coherent sources. Therefore, interference is not observed with two independent bulbs.

(ii) The amplitude of the two interferring sources should be same or nearly same.

(iii) The distance between the two interfering sources S_1 S_2 = d, should be as small as possible.

(iv) The distance of screen from the two interfering sources (D), should be as large as possible.

8. In Young's experiment, if monochromatic source is replaced by a white source coloured fringes are observed. The central fringe is bright and white in colour. Fringe width is least for violet and maximum for red colour.

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9. In Lloyd's single mirror experiment, a source and its reflected image are used as two coherent sources. The *central fringe* in Lloyd's single mirror experiment is *dark.* This is because light in undergoing reflection at plane mirror sufferes a phase change of 180° The condition for constructive interference, in Lloyd's experiment is :

$$\Delta = (2n - 1)\frac{\lambda}{2}$$

10. The colour effects of a thin film are due to interference by multiple reflection and refraction.

11. The bending of waves around an obstacle and their penetration into the region of geometrical shadow is known as the diffraction. Diffraction is shown by all types of waves.

12. To observe, diffraction of light, the obstacle must be *very narrow* (dimensions of obstacle must be comparable to wavelength of light). The shadow of a very thin wire is much broader than expected on the basis of the rectilinear propagation of light. On placing a small circular disc in the path of light, on a screen sufficiently away from disc alternate bright and dark rings are observed with the point on screen corresponding to the centre of the disc, maximum bright as if there was some hypothetical hole in the centre of the disc ! These phenomenon are due to bending of light around the obstacle.

13. When light passes through a slit of width dal a broad principal maxima is observed. The half-angular width of the principal maximum, θ is λ/d. The position of various maxima and minima is given by the conditions:

$d \sin\theta = n\lambda, \quad n \neq 0, \; n = 1, 2, 3, \ldots$ for a minima,

$= (2n - 1)\frac{\lambda}{2}, \quad n = 1, 2, \ldots$ for a maxima.

The single slit diffraction pattern is easily explained using Huygen's principle of secondary wavelets. When the incident wavefront touches the plane of the slit, each point on it (slit) is regarded as source of secondary wavelets. The secondary wavelets interfere with one another producing the single slit diffraction pattern.

We can say, diffraction is interference between different points of the same wavefront.

14. A circular aperture, in the path of light produces diffraction pattern exactly similar to that of a slit, According to *Airy,* the position of first minimum after central maximum is given by the condition $Q = 1.22\frac{\lambda}{d}$.

15. Concept of *rays* can be used conventantly if the angular spread of the beam due to diffraction is negligible compared to the size of the aperture. For an aperture about one mm wide this condition is satisfied over a distance of few metres.

16. Optical instruments like telescope or microscope act as apertures. Light in passing through them undergoes diffraction. The light from a point source appears as a broad maxima of half-angular width λ/d. Two objects are said to be resolved if they are seen separate. According to *Rayleigh,* the two objects are *just resolved,* if the principal maxima in the diffraction pattern of one coincides with the first minimum in the diffraction pattern of the other. This is known as *Rayleigh's criterion.*

17. Polarisation is that property of waves which can distinguish between longitudinal and transverse waves. Longitudinal waves are symmetrical about direction of wave propagation and cannot be polarised. Transverse waves on the other hand do not show this symmetry and can be polarised.

18. Transverse waves in which vibrations take place in *all possible directions,* in a plane perpendicular to direction of wave propagation, are known as *unpolarised.* Light coming from the sun, sodium lamp or incandescent bulb is unpolarised. The tip of electric field vector in an unpolarised beam traces an irregular curve.

19. In a *plane polarised* beam the vibrations of the electric field vector take place in a *particular direction.* The plane containing the direction of vibration and wave propagation is known as the plane of vibration. Plane perpendicular to plane of vibrations is the plane of polarisation.

20. According to Malus' law, the intensity 'I' of plane polarised light transmitted through an analyser is

$$I = I_0 \cos^2\delta$$

where δ is the angle between the plane of the analyser and the plane of polarisation of incident light.

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21. Light, on reflection is partially polarised. If on a plane mirror light is incident at angle of 57°, transmitted light is plane polarised.

According to Brewster's law, the polarising angle of incidence I_p is given by

$$\tan I_p = \mu$$

22. On passing through certain crystals like quartz or calcite, there are two transmitted rays for one incide ray. This kind of refraction of light is known as *double refraction.* Of the two refracted rays, one rotates wh crystal is rotated about incident ray; the other is stationary. The stationary ray is known as O–ray or ordinary r whereas the one that rotates is referred to as the E-rays or Extraordinary ray. The *O-ray obeys Snell's la whereas E-ray does nor obey Snell's law.* The refractive indices of crystal for O-ray and E-ray are different a are denoted by μ_O and μ_e respectively.

23. The apparent change in frequency due to relative motion between source and observer is known Doppler's effect. If a source moves towards an observer at rest, the apparent wavelength λ' is less than t actual wavelength λ. $\Delta\lambda = \lambda - \lambda'$ is known as the *''violet shift''* in wavelength. However, if a source mo away from an observer at rest, the apparent wavelength λ' is more than actual wavelength λ. We say that there a *''red shift''* . The wavelength change.

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$

where v is speed of source of light and c is speed of light in vacuum.

SUBJECTIVE QUESTIONS ON UNIT – VIII

Q.1. *Who first proposed the wave theory of light?*

Ans. Huygen.

Q.2. What is a wavefront?

Ans. The wavefront, at a particular moment of time, is the locus of all those points of the medium that are same phase.

Q.3. What is relation between wavefront and direction of a ray?

Ans. The direction of ray is in the direction of the normal to wavefront.

Q.4. Can two wavefronts cross one another ? Give reasons in support of your answer?

Ans. No. If two wavefronts intersect at a point there are two normals; one to each wavefront, at the point intersection. This means there are two directions of rays at same point. This is not possible. Hence, wavefronts cannot cross one another.

Q.5. *What is the shape of a wavefront from a point source?*

Ans. Spherical with point source as centre of sphere.

Q.6. *A small piece of stone is dropped into a pond of still water. What is the shape of wavefront ?*

Ans. Circular.

Q.7. *What is the shape of a wavefront if a point source is effectively removed to infinity?*

Ans. Plane.

Q.8. *For a parallel beam of light, what is the shape of wavefront?*

Ans. Plane wavefront.

Q.9. *What changes, if any, occur in the shape of a wavefront in a homogenous isotropic medium?*

Ans. In a homogeneous isotropic medium, there is no change in the shape of the wavefront.

Q.10. *What is the shape of wavefront from a line source of light?*

Ans. Cylindrical.

Q.11. *What is the shape of the wavefront for light diverging from a source?*

Ans. A sphere of increasing radius.

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Q.12. *Rays of light converge to a point. Is the radius of wavefront increasing or decreasing?* **(1)**

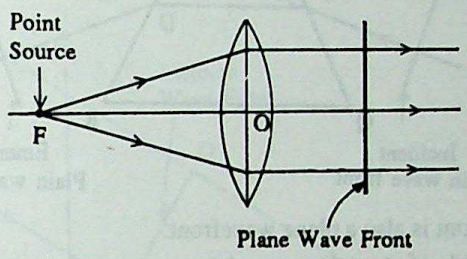
Ans. The radius of wavefront decreased.

Q.13. *A wavefront is spherically decreasing in size. Will the rays constitute a convergent or a divergent beam?*

Ans. Convergent beam.

Q.14. *What is the shape of the wavefront for light emerging from a convex lens having a point source placed at its focus?* **(1)**

Ans. The beam coming out of lens is a parallel beam. Therefore, wavefront of light emerging from convex lens is a plane wavefront. This is shown in Fig. below.

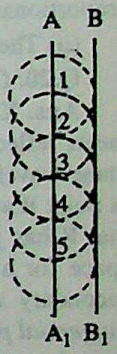


Q.15. *What is the geometrical shape of the part of the wavefront reaching earth from a distant star?* **(1)**

Ans. Since distant star is very far off. The incident beam is a parallel beam. Therefore, wavefront is plane.

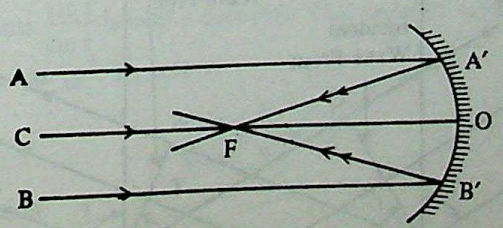
Q.16. *A parallel wavefront advances as a parallel one in a homogenous medium. Justify this statement.* **(2)**

Ans. Let AA_1 be plane wavefront at say t = 0. To find out wavefront t seconds later, we use Huygen's principle. Points like 1, 2, 3, ...etc., on wavefront AB are regarded as hypothetical sources of secondary wavelets. In homogeneous medium the speed of all secondary wavelets is same. In a time t second the secondary wavelets travel a distance = vt, where v is speed of waves in medium. With each point 1, 2, 3, ... as centre draw a sphere of radius vt. The new wavefront BB_1 is the *tangential plane* to all secondary wavelets. From fig. alongside it is obvious that the new wavefront BB_1 is a plane wavefront. Hence, a plane front advances as a plane wavefront.



Q.17. *A plane wavefront meets a concave mirror. What is the reflected wavefront?* **(1)**

Ans. Since the incident wavefront is plane, the incident beam is a parallel beam. After reflection the reflected rays pass through the focus F. The reflected beam is a beam converging towards point F. Hence, the reflected wavefront is a spherical wavefront of decreasing radius.



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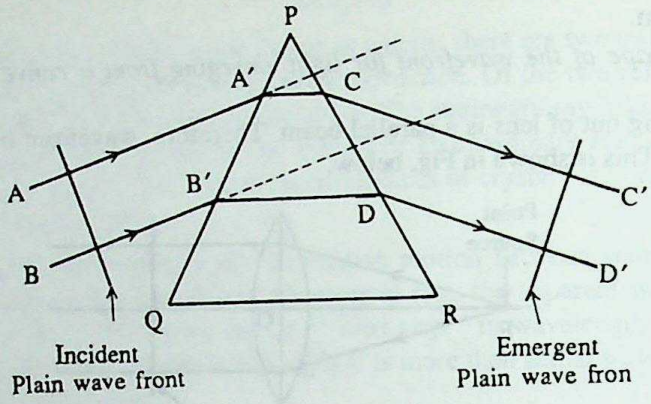
Q.18. *A plane wavefront passes through a prism. What is the transmitted wavefront ?* (1)

Ans. Since the incident plane front is plane, the incident beams, AA′ and BB′ is a parallel beam. CC′ and DD′ is also a parallel beam as shown below.



Hence, the emergent wavefront is also a plane wavefront.

Q.19. *State Huygen's principle of secondary wavelets.* (2)

Ans. According to Huygen's principle :

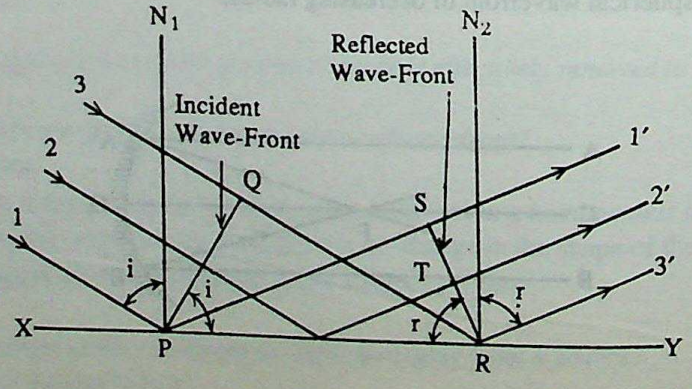
(i) Every point on a given wavefront is regarded as a hypothetical source of secondary wavelets.

(ii) The amplitude of secondary wavelets is in a direction making an angle θ with the forward direction is proportional to $(1 + \cos\theta)$.

(ii) The new wavefront is the *tangential plane* (or *envelope)* of secondary wavelets.

Q.20. *On the basis of Huygen's principle obtain the laws of reflection.* (3)

Ans. XY is a plane reflecting surface. A parallel beam, shown by rays 1, 2 and 3 is incident on XY. Ray 1 meets reflecting surface at P. This moment is chosen as t = 0. The incident wavefront at t = 0 is PQ and is a plane wavefront as shown below. To obtain the *reflected wavefront,* we note that ray 3 meets reflecting surface at point R at t = t. Obviously t = QR/c, where c is speed of light. To obtain reflected wavefront at t = t, we note that R has just become a source of secondary wavelet. The secondary wavelets from P have travelled in the space for a time t. Obviously PS = ct = QR = D. With point P as centre draw a sphere of radius PS. The secondary wavelets from P, at t = t reach the surface of this sphere. The reflected wavefront at t = t is a *tangential plane* from R to this sphere. In other words, RST is the *reflected wavefront.* Since rays are normal to wavefront, the reflected rays 1, 2, and 3 are shown in the figure below. By definition $\angle 1PN_1 = i$ and $\angle 3RN_2 = r$. We know that the angle between two straight lines is same as between their normals. Now XY is $\perp PN_1$ and PQ is $\perp$ 1P. Therefore, $\angle QPR = i$. Similarly, $\angle SRP = r$. In triangles PQR and PSR; PR = QR (common side) QR = PS and $\angle PQR = \angle PSR = \pi/2$. Therefore, triangles PQR and PSR are congruent. Hence, $\angle QPR = \angle SRP$ or i = r. This is the law of reflection.



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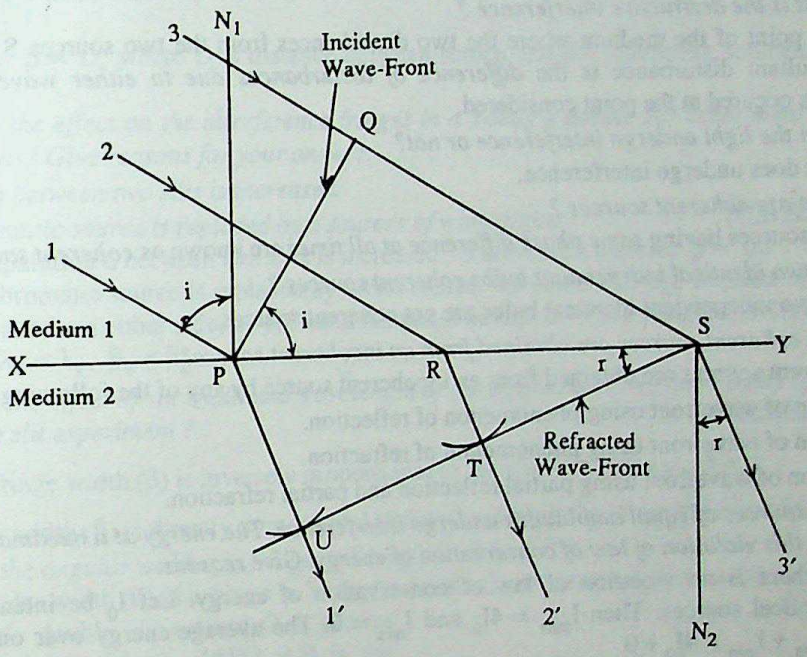
Q.21. *Verify Snell's Law of refraction using Huygen's wave theory.* **(CBSE 1997, 1999) (3)**

Ans. Let XY be a plane surface separating medium I and medium 2 as shown in figure. Speed of light in the two media is v_1 and v_2 respectively. A parallel beam, shown by rays 1, 2 and 3 is incident on XY. Ray 1 meets XY at point P and this time is taken as t = 0. Let ray 3 meets the surface XY at point S at t = t. Obviously, $t = QS/v_1$. To find out the *refracted wavefront* at t = t, we note that secondary wavelets from P have travelled in second medium for t seconds. The distance travelled by these wavelets is $PU = v_2 t = (v_2/v_1)$. With point P as centre draw in second medium a sphere of radius PU. The secondary wavelets from P reach the surface of this sphere at t = t. The refracted wavefront at t = t is the tangential plane from S to these secondary wavelets. This is the plane SU as shown figure below. 8 SU is the refracted wavefront at t = t. The normal to SU at S, R and P gives the refracted rays. By definition $\angle 1PN_1 = i$ and $\angle 3^1SN_2 = r$. Again $\angle QPS = \angle 1PN_1 = i$



and $\angle PSU = \angle 3^1SN_2 = r$.

From right angled ΔPQS

$$\sin i = QS/PS$$

and from right angled ΔPSU

$$\sin r = PU/PS$$

$$\therefore \frac{\sin i}{\sin r} = \frac{QS/PS}{PU/PS} = \frac{QS}{PU} = \frac{QS}{\left(\frac{v_2}{v_1} \cdot QS\right)} = \frac{v_1}{v_2}$$

Since, v_1 and v_2 are constants $\frac{\sin i}{\sin r}$ is also a constant. This constant is refractive index of second medium w.r.t. first medium and is denoted as ${}_1\mu^2$. Therefore,

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = {}_1\mu^2$$

This is snell's law of refraction. **(2)**

Q.22. *Discuss the principle of superposition of waves.*

Ans. Let $\xi_1, \xi_2, \ldots, \xi_N$ be disturbance at a point P of the medium if wave 1, 2, ... ,N is present alone.

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According to the principle of superposition, if all waves are present simultaneously in the medium, the resultant disturbance ξ at point P is

$$\xi = \xi_1 + \xi_2 + ... + \xi_N$$

Q.23. *What is interference of waves ?* (1)

Ans. When two or more than two sources of waves are present simultaneously in a medium, there is *redistribution of energy* in the medium. This is the interference of waves.

Q.24. *What is constructive interference ?* (1)

Ans. At a point of the medium, where the two disturbances from two sources S_1 and S_2 arrive *in phase*, the resultant disturbance is the *sum of disturbances due to each* wave. We say waves have undergone constructive interference at the point considered.

Q.25. *What is the destructive interference ?* (1)

Ans. At a point of the medium where the two disturbances from the two sources S_1 and S_2 arrive *out of phase*, the resultant disturbance is the *difference of disturbances due to either wave.* We say destructive interference has occured at the point considered.

Q.26. *Does the light undergo interference or not?* (1)

Ans. Light does undergo interference.

Q.27. *What are coherent sources ?* (1)

Ans. Two sources having *same phase difference at all times* are known as *coherent sources.*

Q.28. *Are two identical independant bulbs coherent sources ?* (1)

Ans. No, two independent identical bulbs are not coherent sources.

Q.29. *How coherent sources are obtained from an incoherent source?* (2)

Ans. Coherent sources are obtained from an incoherent source by any of the following methods.

(i) Division of wavefront using phenomenon of reflection.

(ii) Division of wavefront using phenomenon of refraction.

(iii) Division of wavefront using partial reflection and partial refraction.

Q.30. *Two sources of equal amplitudes undergo interference. The energy at a maxima is 4 times that due to other source. Is this violation of law of conservation of energy. Give reasons* (2)

Ans. No, there is no violation of law of conservation of energy. Let I_0 be intensity due to either of interferring identical sources. Then $I_{max} = 4I_0$ and $I_{min} = 0$. The average energy over one maximum and one minimum $= \frac{I_{max} + I_{min}}{2} = \frac{4I_0 + 0}{2} = 2I_0$. This equals the total energy due to both sources. In interference there is only *redistribution of energy*. There is no violation of law of conservation of energy.

Q.31. *Define fringe width.* (1)

Ans. The distance between any two consecutive bright or dark fringes is known as fringe width.

Q.32. *In Young's double slit experiment what is the shape of interference fringes ?* (1)

Ans. The fringes are nearly straight lines in shape.

Q.33. *Mention the factors on which the fringe width in Young's double slit experiment depend.* (1)

Ans. The fringe width (β) in double slit experiment is:

(i) directly proportional to wavelength (λ) of light used.

(ii) directly proportional to distance of screen from the two interfering sources (D) and

(iii) inversely proportional to the separation between the two interfering sources (d).

Q.34. *Is central fringe bright or dark in Young's double slit experiment ?* (1)

Ans. In Young's double slit experiment, the central fringe is bright.

Q.35. *What is the distance in terms of fringe width between the central bright and fourth dark fringes in Young's double slit experiment ?* (1)

Ans. The distance between the centeral bright fringe and fourth dark fringe $= 7\left(\frac{\beta}{2}\right)$, where β is the fringe width.

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Q.36. *In Young's double slit experiment, the distance between the two interfering sources is halved. How is fringe width effected?*

Ans. The fringe width becoms double.

Q.37. *In Young's double slit experiment, the source is replaced by another one of shorter wavelength. What happens to the interference fringes ?* **(1)**

Ans. Since $\beta \propto \lambda$; as λ decreases, the fringe width decreases.

Q.38. *What is the effect on the fringe width in Young's double slit experiment if the separation between the slits is increased ?* **(1)**

Ans. Since $\beta \propto \frac{1}{d}$; as d increases, the fringe width decreases.

Q.39. *In Young's double slit experiment, the screen is moved away from the slits. What is the effect on the interference fringes ?* **(1)**

Ans. We know $\beta \propto D$; where D is distance between screen and the interfering sources. As D increases β increases.

Q.40. *What is the effect on the interference fringes in a Young's double slit experiment due to each of the following operations? Give reasons for your answer.*

(a) Separation between two slits is increased.

(b) Monochromatic source is replaced by a sources of white light. **(C.B.S.E. 95 Comptt.) (3)**

Ans. (a) As separation d between two slits is increased, β decreases; because $\beta \propto 1/d$.

(b) As monochromatic source is replaced by white source, the centeral fringe remains bright but is white in colour. It is surrounded, on either side, by coloured fringes. The first coloured fringe is violet and last is red. This is because . Since $\lambda_V < \lambda_R$, $\beta_V < \beta_R$.

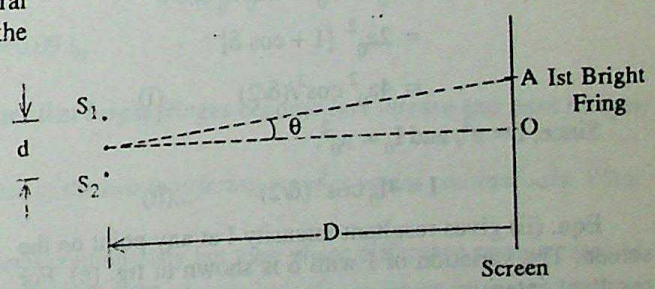
Q.41. *What is the effect of slit width and wavelength of the light source on fringe width of the fringes formed by Young's double slit experiment ?* **(C.B.S.E. 1995 Comptt.) (3)**

Ans. (i) The fringe width (β) is inversely proportional to the slit width (d) i.e., $\beta \propto \frac{1}{d}$

(ii) The fringe width (β) is directly proportional to the wavelength (λ) of the light source, i.e., $\beta \propto \lambda$.

Q.42. *Define the angular width of a fringe in Young's experiment ?* **(1)**

Ans. The angular width (θ) of a fringe in Young's double slit experiment, is the angle subtended by a fringe. shows the Young's double slit set up; O is central fringe and A first bright fringe. $\angle ASO = \theta$ is the angular width of fringe. Obviously ,



$$\tan\theta \approx \theta = \frac{OA}{D} = \frac{\beta}{D}$$

Also $\beta = \frac{\lambda D}{d}$.

Therefore $\theta = \frac{\lambda}{d}$.

Q.43. *How does the angular width of a fringe in Young's experiment change when the distance of the screen from the interfering sources is doubled?* **(1)**

Ans. Remains unaffected. [Refer to angular width expression obtained in Q.42]

Q.44. *What happens to the interference pattern if the two coherent sources in Young's experiment are infinitesimally close to one another ?* **(1)**

Ans. No interference is observed as the two sources merge and become a single source of light.

Q.45. *In Young's double slit experiment three light successively used are : green, yellow and orange. Compare fringe width in three cases.* **(1)**

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Ans. $\beta_g = \frac{\lambda_g D}{d}$; $\beta_y = \frac{\lambda_y D}{d}$ and $\beta_O = \frac{\lambda_O D}{d}$

Since $\lambda_g < \lambda_y < \lambda_O$ $\therefore$ $\beta_g < \beta_y < \beta_O$.

Q.46. *A Young's slit set up is immersed completely in water without any other charge. With happens to the fringe width? Discuss.*

Ans. When Young's double slit set up is immersed completely in water, the wavelength (λ') of source in water is $\lambda' = \frac{\lambda}{\mu}$, where μ is the refractive index of water. Obviously $\lambda' < \lambda$. The fringe width $\beta = \frac{\lambda D}{d}$ and $\beta' = \frac{\lambda' D}{d}$. Clearly $\beta' < \beta$. In words: The *fringe width decreases* when the Young's double slit set up is immersed completely in water without any other change.

Q.47. *In Young's double slit experiment what is the ratio of intensity at a point of constructive and destructive interferences?* (1)

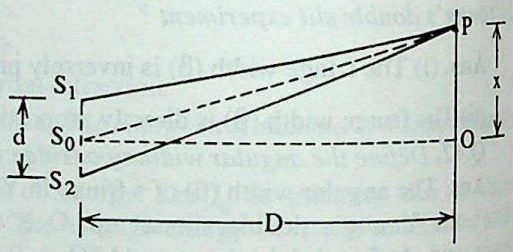
Ans. $\frac{I_{max}}{I_{min}} = \left(\frac{a_1 + a_2}{a_1 \sim a_2}\right)^2$, where a_1 and a_2 denote the amplitude of vibration of source S_1 and S_2 respectively.

Q.48. *Each source in Young's double slit experiment has intensity I_0. What is the intensity at a point of constructive interference ?* (1)

Ans. Intensity at the point of constructive interference $= 4I_0$

Q.49. *Obtain an expression for intensity at any point on the screen in Young's double slit experiment.*

Ans. Fig. (a) shows the Young's double slit set up. S_1 and S_2 are identical sources of intensity I_0. The amplitude of vibration of either source is a_0. Obviously $I_0 \propto a_0^2$. P is any point on the screen where disturbance from S_1 and S_2 arrive having a path difference Δ and phase difference δ. Clearly $\delta = (2\pi/\lambda)\Delta$.. Let a be resultant disturbance at P. To obtain a we vectorially add disturbance at P due to S_1 and S_2. This is shown in Fig. (b). Now



(a)

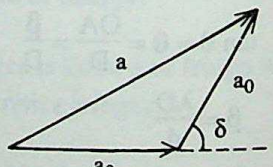
$$a^2 = a_0^2 + a_0^2 + 2a_0\, a_0 \cos\delta$$

$$= 2a_0^2\,[1 + \cos\delta]$$

$$= 4a_0^2 \cos^2(\delta/2) \quad \text{.. (i)}$$

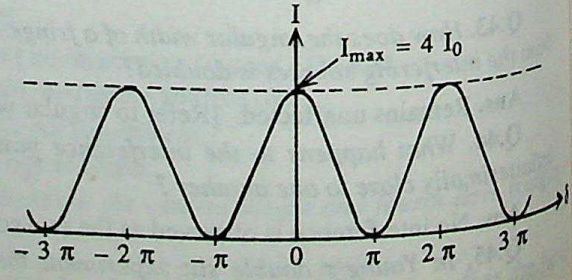
Since, $I \propto a^2$, and $I_0 \propto a_0^2$,

$$I = 4I_0 \cos^2(\delta/2) \quad \text{...(ii)}$$



(b)

Eqn. (ii) gives resultant intensity I at any point on the screen. The variation of I with δ is shown in fig. (c). For resultant intensity to be maximum cos $(\delta/2) = \pm 1$ and $I_{max} = 4I_0$. Though $I_{max} = 4I_0$, there is no violation of law of conservation of energy. The intensity at points of destructive interference $I_{min} = 0$. The average energy over a point of constructive and destructive interference is $(I_{max} + I_{min})/2 = (4I_0 + 0)/2 = 2I_0$, which is the total energy from both S_1 and S_2 taken together. In interference there is a *redistribution* of *energy*. The energy is transferred from a point of destructive interference to a point of constructive interference, but law of conservation of energy remains valid.



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Q.50. *At a point P on a screen in Young's double slit experiment, the two disturbances arrive having a phase difference of 60°. What is the intensity at this point experssed as a fraction of maximum intensity?* **(2)**

Ans. The intensity (I) at a point on screen where the disturbance from the two interfering sources arrive having a phase difference δ is $I = I_{max} \cos^2 (\delta/2)$

Given $\delta = 60^\circ$

$$\therefore \quad I = I_{max} \cos^2 (30^\circ) \text{ or } \frac{I}{I_{max}} = \left(\frac{\sqrt{3}}{2}\right)^2 = \frac{3}{4}.$$

Q.51. *Consider interference between two sources of intensities I_0 and $4I_0$. Obtain intensity at a point where the phase difference is $\lambda/2$.* **(C.B.S.E. 95 Comptt.) (2)**

Ans. Let I_1 and I_2 be intensities of the two interfering sources S_1 and S_2 respectively. The resultant intensity I at a point where phase difference is δ

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos \delta$$

Given $\quad I_1 = I_0, \; I_2 = 4I_0; \; \delta = \pi/2$

$$\therefore \quad I = I_0 + 4I_0 = 5I_0 .$$

Q.52. *What is the nature of the central fringe in Young's double slit experiment when white source of light is used ? Give reasons for your answer.* **(2)**

Ans. The centeral fringe is bright and white in colour. Each white source has constituent wavelengths given by VIBGYOR. Each constituent colour produces its maximum at central point. All these colours recombine to form centeral white fringe.

Q.53. *Of the two slits producing interference in Young's experiment one is covered with glass so that light intensity passing is reduced to 50%. What happens to the intensity of bright and dark fringes?* **(2)**

Ans. Let I_0 be initial intensity of each source. Then $I_{max} = 4I_0$ and $I_{min} = 0$. Let $I' = I_0/2$ be the intensity of source which is covered with glass.

$$\text{Now} \quad I_{max}' = I_0 + \frac{I_0}{2} + 2\sqrt{I_0 I_0/2} = \frac{3I_0}{2} + \sqrt{2}\, I_0 = \left(\frac{3+2\sqrt{2}}{2}\right) I_0 \approx 2.91\, I_0$$

$$\text{and} \quad I_{min}' = I_0 + \frac{I_0}{2} - 2\sqrt{\frac{I_0 I_0}{2}} = \left(\frac{3-2\sqrt{2}}{2}\right) I_0 = 0.09\, I_0 .$$

Obviously $I'_{max} < I_{max}$ and $I'_{min} > I_{min}$. This means that *bright fringes* become *less intense* and *dark fringes* become more intense.

Q.54. *In Young's double slit experiment, the phase of the two interfering sources varies continuously. What happens to the interference pattern ?*

Ans. The phase of the two interfering sources varies continuously but their phase difference remains zero at all time.The interference pattern obtained does not change with time.

Q.55. *Why is it comparatively difficult to observe interference in light waves as compared to water waves* **(2)**

Ans. Wavelength of light waves is very small as compared to wavelength of water waves.

Q.56. *Why interference is not observed with two independent bulbs whereas it is observed with two independent tuning forks ?* **(2)**

Ans. In case of two bulbs, the phase difference between them changes very rapidly ($\sim 10^8$ times in one second). The interference pattern obtained, therefore, changes 10^8 times in 1 second. Such rapid variations eye cannot follow. Therefore, no interference pattern is observed.

For two turning forks of nearly same frequency, the variation of phase is very slow. Consequently, the interference pattern also varies slowly with time. If these variations are less than ~10 per second; human ear can detect these variations, and therefore interference is observable.

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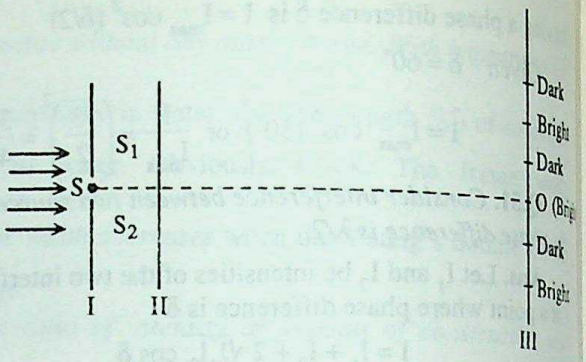
Q.57. *Describe Young's double slit experiment. Obtain an expression for the fringe width. Show that bright and dark fringes are equi-spaced.* (3)

Ans. Fig. alongside shows the essentials of Young's double slit experiment. S, S_1 and S_2 are fine-pin-holes in screen I and II as shown. S_1 and S_2 are equidistant from S. Screen III is at a large distance from screen II. On screen III alternate bright and dark fringes are obtained. O is equidistant from S_1 and S_2 and is known as the *central fringe*. In Young's experiment *central fringe is bright*. On either side of O there are alternate bright and dark fringes. This is known as the interference pattern. To understand Young's interference pattern we refer to Fig. below. Here S_1 and S_2 are two identical sources. P is any point on screen at a distance x from O. The disturbance from S_1 and S_2 reaches P via paths S_1P and S_2P respectively. The path difference, $\Delta = S_2P - S_1P$. Whether point P the is position of a bright or dark fringe depends on value of Δ.

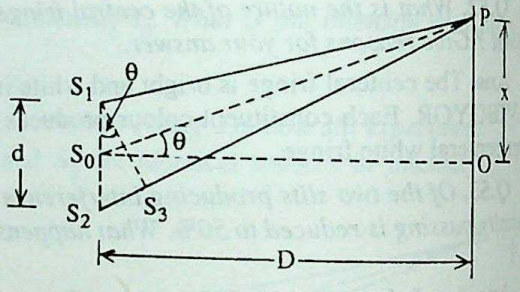


For *constructive interference* (bright fringe)

$$\Delta = n\lambda; \quad n = 0, 1, 2, 3, \quad ...(i)$$

For *destructive interference* (i.e., dark fringe)

$$\Delta = (2n-1)\frac{\lambda}{2}; \quad n = 1, 2, 3. \quad ...(ii)$$



To calculate Δ; in Fig. alongside; with P as centre and S_1P as radius draw an arc meeting S_2P at S_3 Obviously $S_3P = S_1P$ and $\Delta = S_2P - S_1P = (S_3P + S_2S_3) - S_1P = S_2S_3$. Let $S_1S_2 = d$ and $S_2O = D$. In Young's experiment

D >>d. Arc S_1S_3 is almost a straight line and $\angle OSP = \theta$. Now from right angled $\Delta S_1S_2S_3$,

$$\sin\theta \approx \theta = \frac{S_2S_3}{S_1S_2} = \frac{\Delta}{D} \quad ...(iii)$$

From right angled ΔOS_0P, $\tan\theta = \theta \approx \frac{OP}{OS_0} = \frac{x}{D}$ ...(iv)

For *constructive interference*

$$\frac{x_n d}{D} = n\lambda, \; n = 0, 1, 2 \quad ...(v)$$

where x_n is the location of point on screen where n^{th} order constructive interference takes place. The *fringe-width* (β) is the *distance between* any *two consecutive bright fringes*. Obviously

$$\beta = x_{n+1} - x_n = (n+1)\frac{\lambda D}{d} - \frac{n\lambda D}{d} = \frac{\lambda D}{d} \quad ...(vi)$$

Note β does not depend on the value of n. In other words, all *bright fringes are equi-spaced.*

For *destructive interference*

$$\frac{x_n d}{D} = (2n-1)\lambda/2 \text{ or } x_n = (2n-1)\frac{\lambda D}{2d} \quad ...(vii)$$

where x_n is the location of point on screen where n^{th} order destructive interference takes place. The fringe-width (β) for dark fringes is again distance between any two consecutive dark fringes, i.e.,

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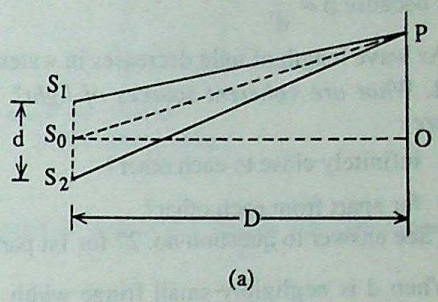
$$\beta = x_{n+1} - x_n = [2(n+1) - 1]\frac{\lambda D}{2d} - (2n-1)\frac{\lambda D}{d} = \frac{\lambda D}{d} \quad \text{... (viii)}$$

Eqn. (viii) clearly shows that β does not depend on the order of interference. In other words, all dark fringes are also *equi-spaced.* Comparing Eqn. (vi) and (vii), we have $\beta = \beta' = \lambda D/d$, i.e., the *fringe, width is same for bright as well as dark fringes.*

Q.58. *Two sources of intensity I_1 and I_2 undergo interference in Young's experiment. Show that* $\frac{I_{max}}{I_{min}} = \left[\frac{a_1 + a_2}{a_1 \sim a_2}\right]^2$, *where a_1 and a_2 are the amplitudes of disturbance from S_1 and S_2.* **(3)**

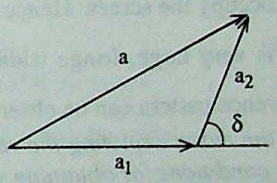
Ans. Fig. (a) alongside shows two coherent sources S_1 and S_2 undergoing interference. I_1 and a_1 denote intensity and amplitude of S_1. I_2 and a_2 are corresponding quantities for S_2. $I_1 \propto a_1^2$ and $I_2 \propto a_2^2$. Let P be any point on the screen . The disturbance from S_1 and S_2 reach point P having a path difference Δ and a phase difference δ. Obviously $\delta = (2\pi/\lambda)\,\Delta = (2\pi/\lambda)\,(xd/D)$. Let a be resultant disturbance at P. To obtain a, we add a_1 and a_2 vectorically. This is shown in Fig. (b). Obviously



(a)

$$a^2 = a_1^2 + a_2^2 + 2a_1 a_2 \cos\delta \quad \text{...(i)}$$

The resultant intensity I at P is proportional to a^2. Eqn (i) can be rewritten as



(b)

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\delta \quad \text{...(ii)}$$

The maximum and minimum values of δ correspond to constructive and destructive interference. For *maximum,* $\cos\delta = +1$ or $\delta = 2n\pi$, n = 0, 1, 2,...

$$I_{max} = I_1 + I_2 + 2\sqrt{I_1 I_2} = a_1^2 + a_2^2 + 2a_1 a_2 = (a_1 + a_2)^2$$

For *minimum* resultant intensity, $\cos\delta = -1$

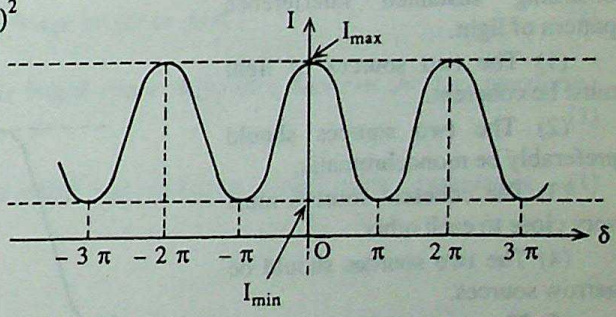
or $\delta = (2n-1)\pi$, n = 1, 2, 3.... From eqn. (ii)

$$I_{min} = I_1 + I_2 - 2\sqrt{I_1 I_2}$$

$$= a_1^2 + a_2^2 - 2a_1 a_2 = (a_1 \sim a_2)^2 \quad \text{...(iv)}$$

From eqns. (iii) and (iv)

$$\frac{I_{max}}{I_{min}} = \left(\frac{a_1 + a_2}{a_1 \sim a_2}\right)^2 \quad \text{...(v)}$$

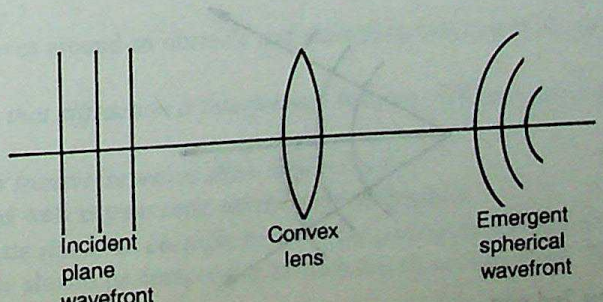


(c)

Fig. (c), above gives variation of I with δ .

Q.59. *Sketch the refracted wavefront emerging from a convex lens if a plane wavefront is incident normally on it.* **(CBSE 1997 Comptt., 1999) (1)**

Ans.



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Q.60. *Derive an expression for the fringe width in Young's douple slit interference experiment.* **(CBSE 1997)(3)**

Ans. See answer to Question 57.

Q.61. *What changes in the interference pattern in Young's double slit experiment will be observed when:*

(i) distance between the slit is reduced?

(ii) the apparatus is immersed in water? **(CBSE 1999)(2)**

Ans. (i) In Young's double slit experiment, when we reduce the distance between the slits, the fringe width increases because $\beta \propto \frac{1}{d}$.

(ii) As wave length of light decreases in water, the fringe width also decreases.

Q.62. *What are coherent sources of light? Why is no inerference pattern observed when two coherent sources are :*

(i) infinitely close to each other?

(ii) far apart from each other? **(CBSE 1998)(3)**

Ans. See answer to question no. 27 for 1st part.

(i) When d is negligibly small fringe width β which is proportional to $\frac{1}{d}$ may become too large. Even a single fringe can occupy the screen. Hence, interference pattern cannot be observed.

(ii) When d is very large, fringe width $\beta \propto \frac{1}{d}$ becomes very small, so that it is beyond the visible region. Hence, no interference pattern can be observed.

Q.63. *Draw the curve depicting the variation of intensity in the interference pattern in Young's double slit experiment. State conditions for obtaining sustained interference pattern of light.* **(CBSE 1999)(3)**

Ans. Following are some important conditions for obtaining sustained interference pattern of light.

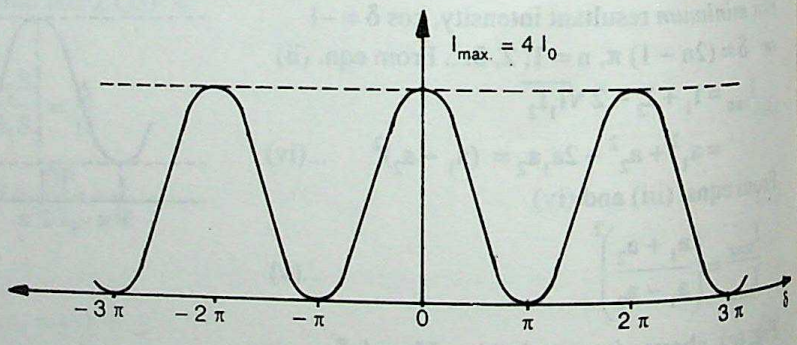
(1) The two sources of light must be coherent.

(2) The two sources should preferably be monochromatic.

(3) The coherent sources must very close to each other.

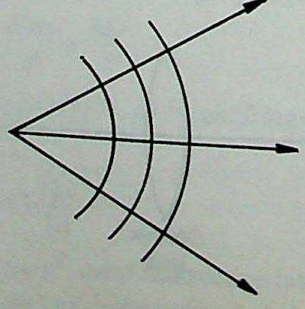
(4) The two sources should be narrow sources.

(5) The two sources should be strong.



Q.64. *Sketch the wavefronts corresponding to converging rays. Verify Snell's law of refraction using Huygen's wave theory.* **(CBSE 1998)(3)**

Ans.



See answer to Q. no. 21 for 2nd part.

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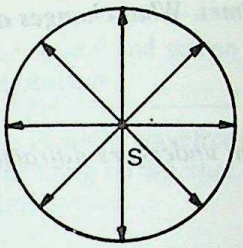
Q.65. *State Huygen's postulates of wave theory. Sketch the wavefront emerging from a (i) point source of light and (ii) linear source of light like a slit.* **(CBSE 2000) (4)**

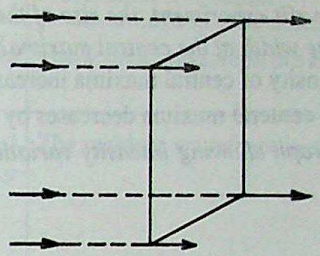
Ans. See answer to Q. no. 19 for 1st part.

(i)



Point source of light

(ii)



Linear source of light

Q.66. *What is the effect on the interference pattern observed in a Young's double slit experiment in the following cases?*

(i) Screen is moved away from the plane of the slits.

(ii) Separation between the slits is increased.

(iii) Widths of the slits are doubled. Give reasons for your answer. **(CBSE 2000) (3)**

Ans. (i) $\beta \propto D$, when screen is moved away from the slits, fringe width increases.

(ii) $\beta \propto \frac{1}{d}$, when the separation between the slits is increased, fringe width decreases.

(iii) When width of the slits are doubled, contrast between maxima and minima decreases due to overlaping of interference patterns.

Q.67. *In Lloyd's single mirror experiment, is central fringe bright or dark ?* **(1)**

Ans. The central fringe is dark.

Q.68. *In Lloyd's single mirror experiment, what is initial phase difference between the two interfering sources ?* **(1)**

Ans. The initial phase difference is π radian.

Q.69. *Write condition of constructive and destructive interference in Lloyd's single mirror experiment.* **(1)**

Ans. Constructive interference

$$\Delta = (2n - 1)\frac{\lambda}{2}, \quad n = 1, 2, 3, ...$$

Destructive interference

$$\Delta = n\lambda, \quad n = 0, 1, 2, 3, ...$$

Q.70. *Name the phenomenon responsible for the exhibition of colours by a thin film of oil.* **(1)**

Ans. The colour effects of thin films are due to interference.

Q.71. *What is diffraction ?* **(1)**

Ans. The bending of waves around an obstacle and their penetration into the region of geometrical shadow is known as diffraction.

Q.72. *Is it correct to say that diffraction is interference between different parts of the same wavefront ?* **(1)**

Ans. Yes.

Q.73. *Do longitudinal or transverse waves show diffraction?* **(1)**

Ans. Both longitudinal as well as transverse waves show diffraction.

Q.74. *What is approximate size of an obstacle so that light undergoes diffraction due to it ?* **(1)**

Ans. The size of obstacle should be comparable to wavelength of light used. The size should be preferably fraction of a millimetre.

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Q.75. *Justify the statement : diffraction is interference between different parts of the same wavefront.* (2)

Ans. When the incident wavefront reaches the obstacle we regard every point on incident wavefront as source of secondary wavelets. The disturbance due to diffracted beam, at any point on screen, is obtained by considering interference between the secondary wavelets. Therefore, diffraction is nothing but interference between different parts of the same wavefront.

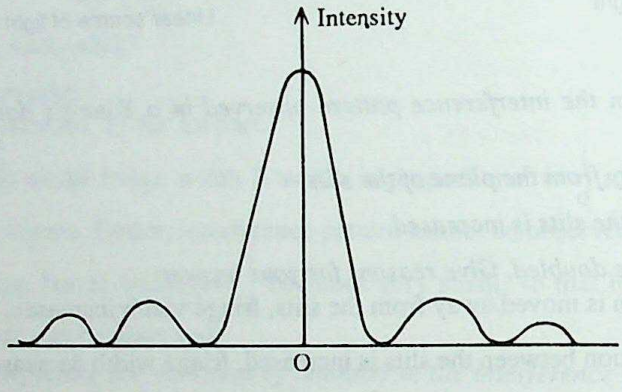
Q.76. *In a single slit experiment, the size of the slit is increased three times. What changes are observed in (i) the intensity (ii) the width of the central maxima?* (2)

Ans. (i) The intensity of central maxima increases by a factor of 9.

(ii) The width of centeral maxima decreases by a factor of 3.

Q.77. *Draw a graph showing intensity variation on a screen when light undergoes diffraction at a single slit.* (1)

Ans.



Q.78. *What is the "half angular width" of the central maximum when light undergoes diffraction at a single slit ?* (1)

Ans. The half angular width (θ) of the principal maxima is $\theta = \lambda/d$, where λ is the wavelength of light and d is the width of slit.

Q.79. *Light undergoes diffraction at a single slit. Write down the condition for maximum and minimum in the diffraction pattern.* (1)

Ans. Let d be width of slit and θ angle of diffraction. Then

For *maxima*: $d \sin\theta = (2n - 1)\frac{\lambda}{2}$ $n = 1, 2, 3,....$

For *minima:* $d \sin\theta = n\lambda$ $n \neq 0$; $n = 1, 2, 3,.....$

$n = 0$; gives the condition for central maxima (or principle maxima).

Q.80. *Is the intensity of central maxima more, less or equal to the intensity of the first maxima in the diffraction pattern of a single slit ?* (1)

Ans. The intensity of central maxima is *more* than the intensity of the first maxima.

Q.81. *A small circular disc is placed in the path of light from a distant source. Will the centre of shadow be bright or dark ?* (1)

Ans. The centre of the shadow is bright. (1)

Q.82. *What is Fraunhoffer diffraction ?*

Ans. If incident beam is a parallel beam (i.e., incident wavefront is a plane wavefront) we have Fraunhoffer diffraction. (1)

Q.83. *What is Fresnel diffraction ?*

Ans. In Fresnel's diffraction, the source is at a finite distance from the obstacle. The incident wavefront is spherical for a point source of light.

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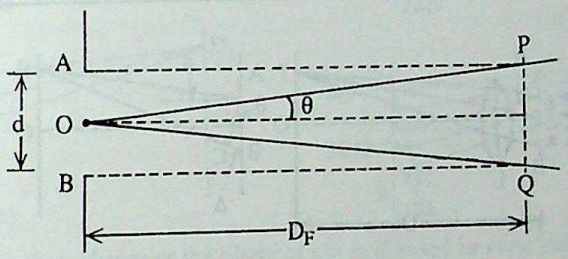
Q.84. *Distinguish between Fresnel and Fraunhoffer diffraction* **(2)**

Ans.

S. No.	Fresnel diffraction	Fraunhoffer diffraction
(i)	The source and screen are at finite distance from the obstacle.	The source and screen are effectively at infinity.
(ii)	The incident wavefront is spherical or cylindrical depending on whether source is a point source or a line source.	The incident wavefront is plane.

Q.85. *What is Fresnel distance ?* **(1)**

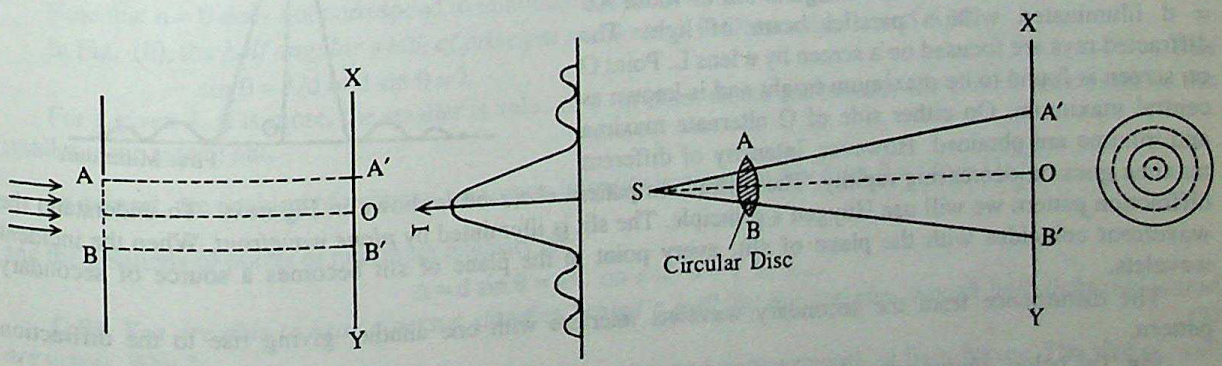
Ans. The Fresnel distance (D_F) is the distance from obstacle where the linear width of the diffracted beam equals width of aperture. This is as shown below.



AB = d = Width of aperture. OP and OQ are diffracted rays. θ is half angular width of principal maximum.

Q.86. *Give two experiments exhibiting diffraction of light.* **(2)**

Ans. In Figure given below, AB is a narrow slit of width d illuminated with a parrallel beam. XY is a screen at a large distance from AB. The variation of intensity (I) on screen is as shown in figure (a) below. Obviously light is penetrating into the region of geometrical shadow.



In Fig. (b) above, S is a monochromatic point source of light. AB is a circular disc of small size placed in the path of light. A′ B′ is region of geometrical shadow on screen XY. The central point O on screen is observed to be maximum bright.

It is surrounded by alternate bright and dark rings as shown in Fig.

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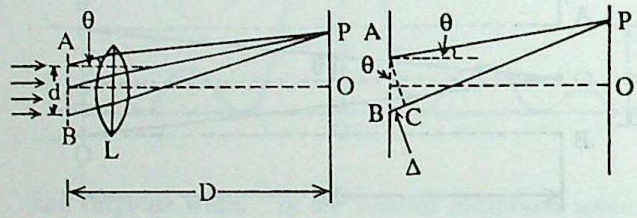
Q.87. *Give points of difference between the phenomenon of interference and diffraction.*
(C.B.S.E. 1995, 97 Comptt.) (2)

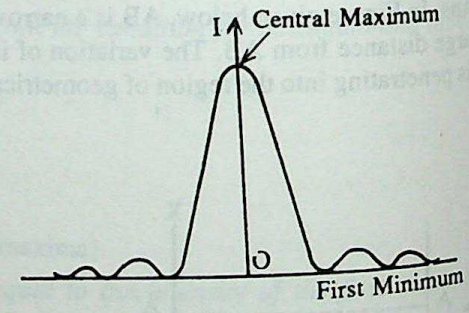
Ans.

S. No.	Interference	Diffraction
(i)	Interference is due to superposition of two coherent waves.	Diffraction is due to interference between different parts of same wavefront.
(ii)	All fringes are equispaced. or Fringe width is constant.	Fringes are not equispaced. or Fringe width is not a constant.
(iii)	Intensity of all bright fringes is same.	The intensity of all bright fringes is not same. The central maximum is most intense.
(iv)	Number of fringes observed is quite large. (~20 to 30)	Number of fringes observed is small. (~ 4 – 8)



Q.88. *Discuss in detail, the diffraction pattern of a single slit of width d. Obtain an expression for the half angular width of the principal maxima.* (3)

Ans. The bending of light around an obstacle and penetration into the region of geometrical shadow is the diffraction of light. In order that diffraction be observable the size of obstacle must be comparable to wavelength of light. Fig. alongside shows a rectangular slit of width AB = d illuminated with a parallel beam of light. The diffracted rays are focused on a screen by a lens L. Point O on screen is found to be maximum bright and is known as central maximum. On either side of O alternate maxima and minima are obtained. However, intensity of different maxima goes on decreasing rapidly. The diffraction pattern observed is shown in Fig next. To understand the diffraction pattern we will use Huygen's principle. The slit is illuminted by *plane wavefront.* When the incident wavefront coincides with the plane of slit, every point in the plane of slit becomes a source of secondary wavelets.



The disturbance from the secondary wavelets interfere with one another giving rise to the diffraction pattern.

Fig. (a) below shows secondary wavelets from the plane of slit reaching central point O. Obviously all secondary wavelets reach P in *same phase* and undergo *constructive interference* producing a maximum at O.

Fig. (b) below shows secondary wavelets from the plane of slit reaching point D_1. D_1 is the position of first *dark fringe.* D_1 is such that $BD_1 - AD_1 = \lambda$. from A draw AC perpendicular to BC. In diffraction experiment d << D, therefore $AD_1 = CD_1$ and $BD_1 - AD_1 = BC$, O_1 is the mid-point of slit. Obviously $O_1O_2 = \lambda/2$. The

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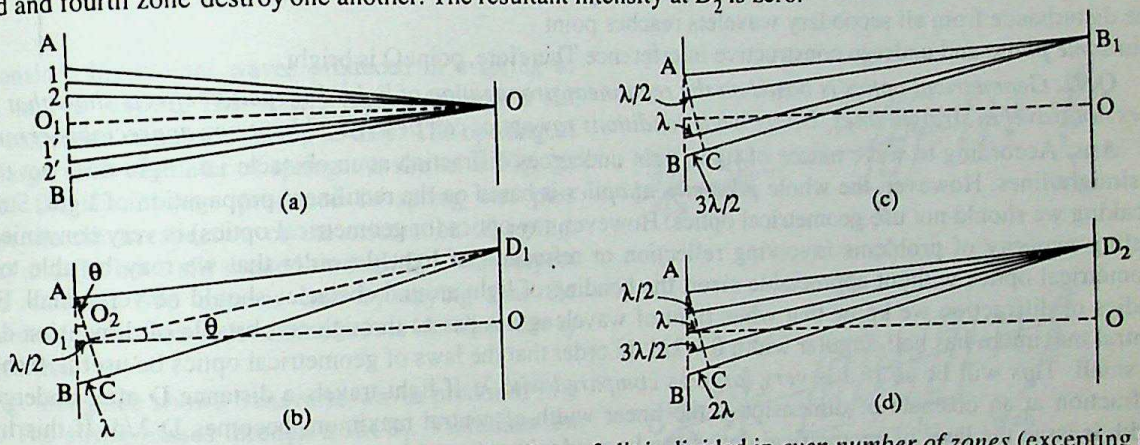
secondary wavelets from A and O_1 have a path difference $\lambda/2$ and undergo destructive interference at D_1. For every point in the upper half AO_1 of wavefront there is a corresponding point in the lower half O_1B of wavefront such that the two disturbances reach D_1 out of phase and undergo destructive interference. Hence resultant intensity at D_1 is zero due to the entire wavefront AB. We say AO_1 and O_1B are the two "*zones*" into which wavefront has been divided. The two zones destroy one another producing minimum at D_1.

Fig. (c) below shows the first maximum after central maximum at point B_1. For point B_1, $BB_1 - AB_1 = 3\pi/2$. Divide the wavefront into three zones. The first two zones destroy one another undergoing destructive interference. The resultant intensity at B_1 is only due to one zone. This maximum, therefore, is much less intense than central maximum at O.

Fig. (d) below shows second minimum at point D_2. For D_2, $BD_2 - AD_2 = 2\lambda$. Divide the plane of slit into four equal parts (i.e., four zones). The first and second zone undergo destructive interference. Similarly, the third and fourth zone destroy one another. The resultant intensity at D_2 is zero.



We can generalise and say that whenever the plane of slit is divided in *even number of zones* (excepting two zones) we have minimum intensity on screen.

If, however, the plane of slit is divided into *odd number of zones* we have maximum intensity of screen. Let P be any point on screen. Then for *maximum intensity,*

$$\Delta = BP - AP = (2n + 1)\,\lambda/2, \quad n = 1, 2, 3.... \qquad ...(i)$$

and *for minimum intensity,*

$$\Delta = BP - AP = n\lambda;\ n \neq 0;\ n = 1, 2, 3..... \qquad ...(ii)$$

Note that n = 0 does not correspond to minimum intensity but gives the principle maximum.

In Fig. (b), the *half angular width of principal maximum is* θ. Obviously, from Δ ABC

$$\sin\theta = \lambda/d \text{ or } d\sin\theta = \lambda \qquad ...(iii)$$

For a given λ, θ is more, the smaller is value of d. In other words the broader the central maximum is, the smaller is the size of slit.

In general, the position of points of maximum intensity is given by $\Delta = d\sin\theta = (2n + 1)\dfrac{\lambda}{2}$

and the positions of points of minimum intensity are

$$\Delta = d\sin\theta = n\lambda, \text{ on} \neq 0;\ n = 1, 2, 3....$$

Q.89. *You are able to hear a person standing behind a wall but not see him, though both light and sound are waves. Why ?* **(2)**

Ans. Wavelength of sound waves is very large as compared to wavelength of light waves. The size of wall is comparable to wavelength of sound. Therefore sound waves undergoing diffraction around wall reach the person standing behind wall. However, size of wall is very-very large as compared to wavelength of light. Light, therefore, does not undergo observable diffraction around wall and therefore one cannot see person standing behind a wall.

Q.90. *Radio waves undergo diffraction easily around buildings. Light waves are also electromagnetic*

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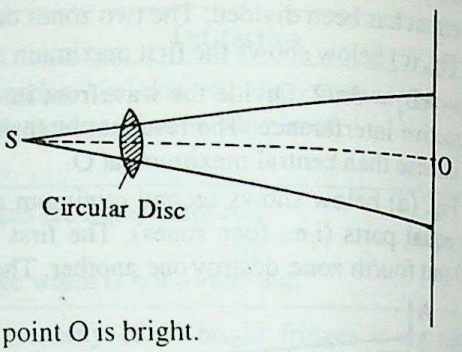
waves like radio waves. Why does light not diffract around buildings? Explain. (2)

Ans. Wavelength of microwaves is large. It is comparable to size of building. Therefore radio waves undergo diffraction easily around buildings. However wavelength of *visible light* is very-very small as compared to size of building. Therefore visible light does not undergo diffraction around buildings.

Q.91. *A small circular disc is placed in the path of light from a distant source. The centre of shadow is bright. Explain*

Ans. Fig. alongside shows a circular disc placed in path of light from source S. According to Huygen's principle every point in plane of disc becomes a source of secondary wavelets when incident wavefront reaches it. The disturbance from all secondary wavelets reaches point O in *same phase* and undergo constructive interference Therefore, point O is bright.



Q.92. *Geometrical optics is based on the rectilinear propagation of light. Diffraction effects show that light does not travel in straight lines. Under what conditions ray optics can be used without any appreciable error.* (2)

Ans. According to wave nature of light, light undergoes diffraction at an obstacle i.e., light does not travel in straight lines. However, the whole *geometrical optics* is based on the rectilinear propagation of light. Strictly speaking we should not use geometrical optics. However, ray optics (or geometrical optics) is very convenient in dealing majority of problems involving reflection or refraction of light. In order that we may be able to use geometrical optics without appreciable error, the bending of light around obstacles should be very small. From studies of diffraction we know that when light of wavelength λ passes through an obstacle of dimension d, the central maximum has half-angular width $\theta = \lambda/d$. In order that the laws of geometrical optics be useful, θ should be small. This will be so if d is *very large* as *compared with* λ. If light travels a distance D after undergoing diffraction at an obstacle of dimension d the linear width of central maximum becomes $D\,\lambda/d$. If this linear width is large the laws of geometrical optics can be used without much error. Let D_F be distance at which linear width of diffracted beam equals the size of obstacle.

i.e., $\lambda D_F/d = d$ or $D_F = d^2/\lambda$. D_F is known as Fresnel's distance. In case $D > D_F$ laws of geometrical optics can not be used without appreciable error. However if $D < D_F$ laws of geometrical optics should be used. For a lens of aperture d = 1 cm and $\lambda = 600$ *nm*, $D_F = (10^{-3})^2/6\times 10^{-7} \sim 1.7$m. Thus, laws of geometrical optics can be used conveniently for distance greater than about 1.7 m. (2)

Q.93. *A single slit diffraction set up is immersed completely in water without any other change. How is the width of the central maximum affected ?* (1)

Ans. The angular width (θ) of centeral maxima is : $\theta = \lambda/d$. When the single slit diffraction apparatus is immersed completely in water, λ decreases therefore θ also decreases. (2)

Q.94. *What do you understand by the term polarisation?*

Ans. The process of restricting vibrations of electric field, in light waves, to a particular direction only is known, as polarisation of light. (1)

Q.95. *What is unpolarised beam of light ?*

Ans. In an *unpolarised* beam of light the electric field can vibrate in *any direction* perpendicular to the direction of wave prapagation. (1)

Q.96. *What is plane-polarised light ?* (1)

Ans. A beam of light in which vibrations of electric field occur only in a particular direction is known as a plane polarised beam. (2)

Q.97. *Light coming from sun is polarised or unpolarised. Explain.*

Ans. Unpolarised. The vibrations of electric field take place in every possible direction, in a plane perpendicular to the direction of propagation of light. (1)

Q.98. *Can longitudinal waves be polarised ?*

Ans. No.

Q.99. *Can transverse waves be polarised?*

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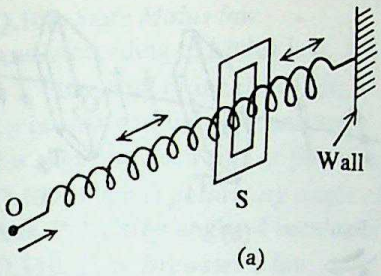
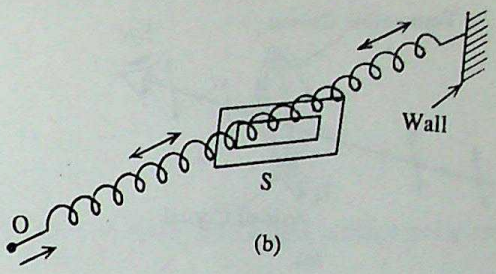
Ans. Yes.

Q.100. *Describe in detail a mechanical experiment to distinguish between longitudinal and transverse waves.* **(3)**

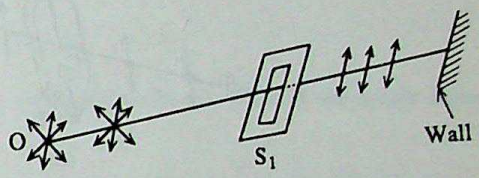


(a)

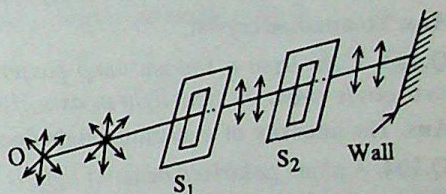


(b)

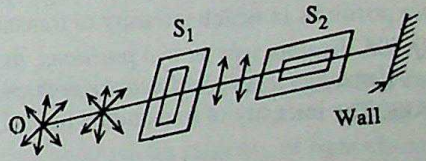
Consider logitudinal waves produced in a spring as shown in Fig. above. The spring passes through a slit which can rotate about the spring as axis. The opening of slit is larger than diameter of spring. As shown in Fig. (a) and (b) the disturbance produced in spring can pass through the slit irrespective of the orientation of spring. Fig. (a) and (b) have slit rotated through 90° with respect to one another. We express this by saying that the *longitudinal waves are symmetrical about the direction of propagation.*



(a)



(b)



(c)

Fig. alongside shows transverse waves produced in a string. The string passes through a slit S_1. Vibrations are produced in *all directions* at right angles to the slit in the part OS_1 of string. The slit S_1 blocks all vibrations except vibrations in a direction parallel to slit as shown in Fig. alongside (a). Waves produced in part OS_1 which do not have vibrations in any *preferred direction* are known as *unpolarised* waves. The waves in part S_1A have a particular direction *of vibration.* These waves are known as plane polarised. *Fig (b)* shows string passing through two slits S_1 and S_2. When S_1 and S_2 are parallel vibrations are present in part S_2 in a position 90° apart from the position of S_2 in Fig (b). The vibrations that are passed through S_1 are blocked by S_2. There are no vibrations in part S_2A of string. On rotating S_2 through a complete circle there are two positions of S_2 in which no vibrations pass through it and there are two positions in which all vibrations pass through. This behaviour is a characteristic of transverse waves only and hence transverse waves can be distinguished from longitudinal waves. We also express this fact by saying that *longitudinal waves* cannot be *polarised,* whereas *transverse waves can be polarised.* For transverse waves slit S_2 is known as *polariser* and slit S_2 is known as *analyser.* **(2)**

Q.101. *Draw the outline of the experiment which shows that light waves are transverse in nature.*

Ans. Light from a source S is passed through a *tourmaline crystal* and the light transmitted is seen as shown in Fig. (a), below. On passing through the tourmaline crystal the light acquires some colour due to crystal. There is no change in *intensity of transmitted light* as crysial T_1 is rotated about incident ray as axis.

Fig. (b), below shows two tourmaline crystals T_1 and T_2. The axis of the two crystals are parallel to one another. Light transmitted through T_1 is also able to pass through T_2. Keeping T_1 fixed rotate T_2, about the incident ray as axis.

The intensity of light transmitted through T_2 starts decreasing. When T_2 is rotated through an angle of $\pi/2$ w.r.t to T_1 as shown in Fig (c), no light is transmitted through T_2. The intensity of transmitted light is zero. In

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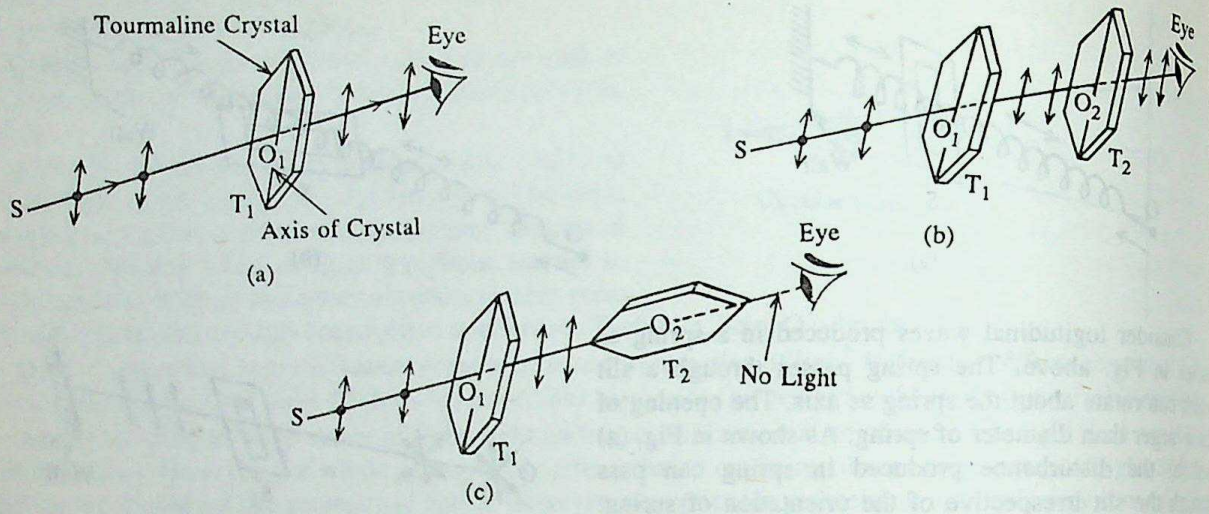
one complete rotation of T_2, there are two positions in which the light transmitted through T_2 has maximum intensity and two positions in which the intensity of transmitted light is zero. This behaviour is a characteristic of transverse waves. Hence, light waves are transverse in nature.



Q.102. *Name a crystal used commonly to polarise a beam of light.* (1)

Ans. Tourmaline crystal.

Q.103. *Light from a sodium lamp passes through a tourmaline crystal. The crystal is rotated through a complete circle about incident light as axis. How the intensity of transmitted light varies ?* (1)

Ans. The intensity of transmitted light does not vary. The light from sodium lamp is unpolarised.

Q.104. *A plane polarised beam of light is incident on a tourmaline crystal. The crystal is rotated through a complete circle about incident light as axis. What charges in intensity of transmitted light are observed ?* (1)

Ans. The intensity of transmitted light varies from a maximum value to zero. In one complete rotation there are two positions in which intensity of transmitted light is zero.

Q.105. *Explain why in two positions, the intensity of transmitted light is zero when a plane polarised beam is viewed through a polaroid and the polaroid is rotated about the incident ray as axis ?* (2)

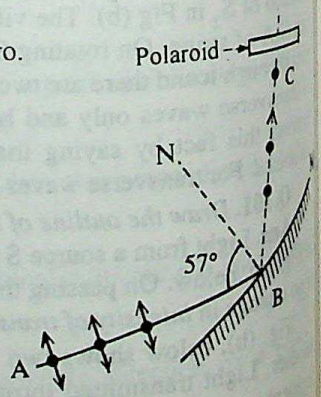
Ans. The intensity of transmitted light (I) viewed through a polaroid is

$$I = I_0 \cos^2 \delta$$

where I_0 is intensity of incident light and δ is angle between the plane of polarisation and axis of polaroid. Obviously, $I = 0$ if $\delta = \pi/2$ or $3\pi/2$.

These are the two positions in which the intensity of transmitted light is zero.

Q.106. *Name the various processes used to polarise an unpolarised beam of light. Discuss, in detail, polarisation by reflection.* (3)



Ans. The various processes used to polarise an unpolarised beam of light are :

(i) reflection (ii) refraction (ii) partial reflection and refraction (iv) selective absorption (v) scattering.

Polarisation by reflection : In Fig. below, M is a plane mirror. A beam of light AB is incident on M at an angle of 57°. The reflected ray BC is made to pass through a polaroid. On rotating polariod, about BC as axis, through one complete circle, there are two positions of polaroid in which intensity of transmitted light is zero. This shows that reflected beam BC is plane polarised. The angle of incidence of 57° is known as the polarising angle of incidence (i_p)

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Q.107. *A beam of light is incident on a polaroid. On rotating the polaroid through one complete circle about the incident ray as axis the intensity of transmitted light varies between a maximum and a non-zero minimum. What is the state of polarisation of the incident beam* **(1)**

Ans. Partially polarised or mixture of unpolarised and plane polarised light.

Q.108. *State Malus law.* **(1)**

Ans. According to Malus law, $I = I_0 \cos^2 \delta$,

where I_0 - intensity of incident light,

I = intensity of light transmitted

δ = angle between axis of polariser and analyser.

Q.109. *What is polarising angle of incidence ?* **(1)**

Ans. Polarising angle of incidence (i_p) is angle of incidence so that reflected light is plane polarised.

Q.110. *State Brewster's law.* **(1)**

Ans. According to Brewster's law, $\tan i_p = \mu$

where i_p = polarising angle of incidence

μ =refractive index of reflector.

Q.111. *Light is incident on a surface at the polarising angle of incidence. What is the angle between the reflected and refracted ray ?* **(1)**

Ans. 90°

Q.112. *A polariser and analyser are so oriented that intensity of light transmitted is maximum. What fraction of maximum light is transmitted when analyser is rotated through an angle of 60°?* **(1)**

Ans. $\delta = 60°$. According to Malus law.

$$I = I_0 \cos^2 60° = \frac{I_0}{4}$$

$$\therefore \frac{I}{I_0} = \frac{1}{4}$$

Q.113. *A polariser and analyser are so oriented that no light is transmitted. What is the angle between the axis of the analyser and polariser ?* **(1)**

Ans. 90°

Q.114. *How can one distinguish between an unpolarised light beam and a linearly polarised light beam using a polaroid?* **(CBSE 1996) (2)**

Ans. When a beam of linearly polarised light is seen through a polaroid the intensity of light changes as the polaroid is rotated. However, if a beam of unpolarised light is seen through a polaroid, the intensity of light does not change as the polaroid is rotated through 360°.

Q.115. *Derive an expression for the width of the central maxima for diffraction of light at a single slit. How does this width change with increase in width of the slit?* **(CBSE 1998) (3)**

Ans. See answer to question 88 for 1st part. With increase in the width of the slit, width of central maximum decreases.

Q.116. *Why is diffraction of sound waves easier to observe than diffraction of light waves? What two main changes in diffraction pattern of a single slit will you observe when the monochromatic source of light is replaced by a source of white light?* **(CBSE 1997) (3)**

Ans. Diffraction of waves is observed only when their wavelength is of the order of size of the obstacle. Wavelength of sound waves in large. It is comparable to size of the obstacle. Therefore, soundwaves undergo diffraction easily. However, wavelength of visible light is very-very small as compared to the obstacle. Therefore visible light does not undergo diffraction around the obstacle.

When a monochromatic source of light is replaced by a source of while light, the diffraction pattern is coloured. The central maximum is white but other bands are coloured.

Q.117. *How would you show experimentally that light waves are transverse?* **(CBSE 1999) (2)**

Ans. By polarization of light using Nicol prism, we can show that light waves are transverse.

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Q.118. *In a single slit diffraction experiment, if the width of the slit is doubled, how does the (i) intensity of light (ii) width of central maximum change? Give reasons for your answer.* **(CBSE 2000)** (2)

Ans. (i) Intensity of light gets doubled because intensity $\propto$ slit width.

(ii) Width of central maximum becomes one-half because $\beta \propto \frac{1}{\propto}$.

Q.119. *Explain, why on viewing clear blue part of the sky through a polariod the intensity of transmitted light varies as polaroid is rotated?* (2)

Ans. The blue of the sky is due to scattering of light. The scattered light is *partially polarised.* When this light is viewed through a polariser the intensity of transmitted light varies as polariod is rotated.

Q.120. *What is the percentage of incident light transmitted if the angle between polariser and analyser is 30° ?* (1)

Ans. Given $\delta = 30°$, According to Malus law.

$$I = I_0 \cos^2 30 = I_0 (3/4)$$

$\therefore$ Percentage of incident light transmitted

$$= \frac{I}{I_0} \times 100 = \frac{3}{4} \times 100 = 75\%.$$

Q.121. *Two polaroids are placed at 90° to each other. The intensity of transmitted light is zero. Another polaroid is introduced between the two making an angle of 45° with either. What is the intensity of light transmitted ?* (2)

Ans. Let I_0 be intensity of light incident on first polaroid. The angle between axis of first and 2nd polaroid is 45°. Let I_1 be intensity of light transmitted. Then,

$$I_1 = I_0 \cos^2 45° = \frac{I_0}{2}$$

The intensity of light incident on third polarised is $\frac{I_0}{2}$. The angle between axis of second and third polaroid is 45°. Let I_2 be intensity of light transmitted through third polaroid. Then,

$$I_2 = I_1 \cos^2 45° = \frac{I_1}{2} = \frac{I_0}{2} \times \frac{1}{2} = \frac{I_0}{4}.$$

Q.122. *Show that at the polarising angle of incidence the reflected and transmitted rays are at right angles to one another.*

Ans. According to Brewster's law, if light ungergoes reflection at a particular angle i_p known as *polarising angle of incidence* the reflected light is plane polarised. Also $\mu = \tan i_p$, where μ is the refractive index of medium where reflection takes place. Fig below shows a ray OA incident at polarising angle of incidence i_p. OB and OC are the reflected and transmitted rays Obviously $\angle AON = \angle BON = i_p$. From Snell's law

$$\mu = \sin i_p / \sin r \quad ...(i)$$

From Brewster's law

$$\mu = \tan i_p = \sin i_p / \cos i_p \quad ...(ii)$$

From Eqns. (i) and (ii)

$$\cos i_p = \sin r \text{ or } \sin(\pi/2 - i_p) = \sin r$$

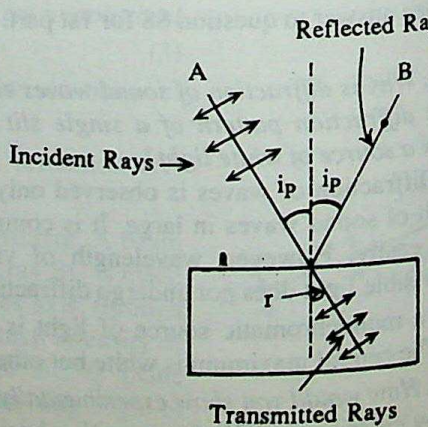
$$\therefore \pi/2 - i_p = r \text{ or } i_p + r = \pi/2 \quad ...(iii)$$

From Fig.

$$\angle N_1OB + \angle BOC + \angle CON_1 = \pi$$

or $i_p + \angle BOC + r = \pi$

$$\therefore \angle BOC = \pi - \pi/2 = \pi/2$$



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$\angle BOC$ is the angle between the reflected and transmitted rays. Therefore, at the polarising angle of incidence, the reflected and transmitted rays are at right angles to one another.

Q.123. *A dot of ink on a drawing sheet is viewed through a calcite crystal. How many refracted images will be seen ?* **(1)**

Ans. Two

Q.124. *What is Doppler's effect ?* **(1)**

Ans. The apparent change in frequency of waves due to *relative motion* between source and observer is known as the Doppler's effect.

Q.125. *A source of waves approaches a stationary observer. How is the apparent frequency of the source related to its true frequency ?* **(1)**

Ans. $n' = n\dfrac{v}{v - v_s}$, n = actual frequency, n' = apparent frequency, v = speed of waves, v_s = speed of source.

Q.126. *An observer moves away from a stationary source of waves. How is the apparent frequency of the source related to its true frequency ?* **(1)**

Ans. $n' = n\left[\dfrac{v - v_0}{v}\right]$

n' = apparent frequency, n = actual frequency, v = speed of waves, v_0 = speed of observer

Q.127. *Does the Doppler's shift in the frequency of a light source depend on whether the source or the observer is moving ? State the relevant formula for either case.* **(2)**

Ans. Yes.

When source of light moves towards a stationary observer, with a speed v_s; the apparent frequency n' is

$$n' = \frac{n}{\left[1 - \dfrac{v_s}{c}\right]} = n\left[1 - \frac{v_s}{c}\right]^{-1} = n\left[1 + \frac{v_s}{c}\right]$$

Q.128. *Explain in brief, how the traffic police may make use of Doppler's effect in estimating the speed of a moving vehicle ?* **(3)**

Ans. When radio waves from a radar are made to fall on a moving car the car acts as a reflector. The reflected waves appear to come from an apparent source moving with a *speed twice the speed of car.* Since the apparent source of reflected waves is moving towards observer at rest it undergoes a *Doppler's shift.* The apparent source of reflected waves is moving towards observer at rest it undergoes a *Doppler's shift.* The *Doppler's shift* depends on speed of apparent source. If Doppler's shift is measured the speed of approach of apparent source and therefore speed of car is calculated.

Q.129. *If the light 'from the stars were to show a blue shift', what could we say about the direction of motion of stars ?* **(2)**

Ans. A blue shift means that apparent wavelength (λ') is less than the actual wavelength (λ). This means that star is moving *towards earth.*

Q.130. *What is meant by 'Red shift' and 'Blue Shift' in connection with the Doppler effect ? Explain the significance, if any, of these shifts in connection with the theory of the origin of universe.* **(3)**

Ans. A "red shift" means that apparent wavelength (λ') is more than the actual wavelength (λ). This happens when the source, say a star, is moving away from observer at rest on earth.

A "blue shift" means that apparent wavelength (λ') is *less* than the actual wavelength (λ) This happens if the source, say a star, moves towards an observer at rest on earth.

These shifts allow us to know whether a star is moving towards or away from earth. According to the "*big-bang*' theory the various objects in universe are moving away from one another. The observed "red-shift" in the wavelength of light from stars supports the big-bang theory.

Q.131. *What is Doppler's effect for light ? Obtain an expression for the apparent frequency of light when a source moves (i) towards and (ii) away from a stationary observer. What is apparent frequency if source is at rest and observer is in motion.* **(3)**

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Ans. The apparent change in the frequency of a wave due to relative motion between the observer and source is known as Doppler's effect. According to Doppler's principle, there is an *increase in apparent frequency of* light *when the source moves towards observer and* vice-versa.

CASE I : Observer at rest, source in motion

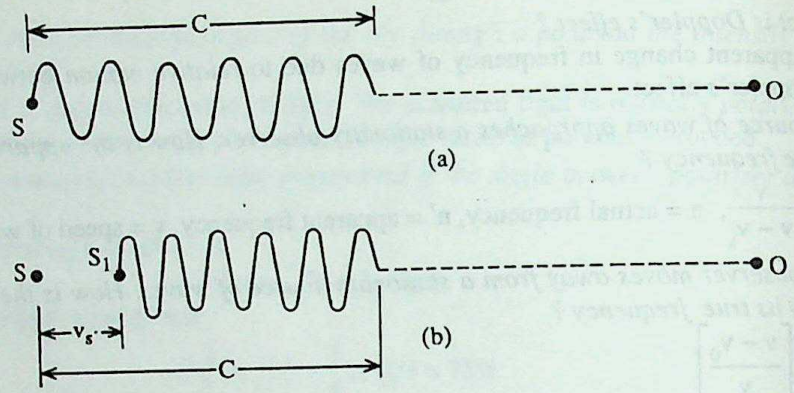

Fig (a) shows a source S and observer O at *rest.* The actual frequency of source is n. This means that source emits n waves each of wavelength $\lambda = c/n$ as shown in Fig (a). The source starts vibrating at t = 0 and in one second the disturbance travels a distance SA = c. There are n, *equi spaced* waves in distance SA. In Fig (b) the source S moves towards observer O with a speed v_s . S is position of source at t = 0 and S_1 its position one second later. Obviously $SS_1 = v_s$. The source emits first wave when it is in position S and the nth wave when it is at S_1. In one second the first wave travel distance SA = c′. Now n waves are confined within distance $S_1A = SA - SS_1 = c - v_s$ The apparent wavelength $\lambda_1 = (c - v_s)/n$. Therefore the apparent frequency n_1 is

$$n_1 = c/\lambda_1 = n\,c/(c - v_s)$$

or

$$n_1 = \frac{n}{\left(1 - \frac{v_s}{c}\right)} \quad \ldots(i)$$

If the source moves away from the observer, the apparent frequency n_2 is obtained by replacing v_s by $-v_s$ in Eqn (i).

Therefore ,

$$n_2 = \frac{n}{\left(1 + \frac{v_s}{c}\right)} \quad \ldots(ii)$$

CASE II : Source at rest observer in motion

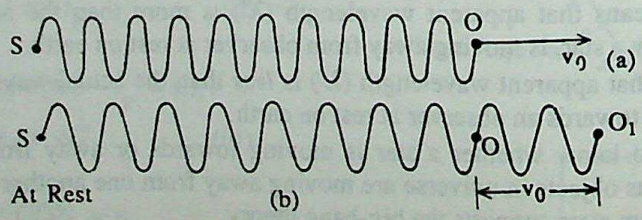

Fig. (a), above shows an observer O moving away from a source S with a speed v_0. The source S being at rest emits n waves each of wavelength $\lambda = c/n$; per second. If observer is at rest, n waves cross observer in

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second. In Fig (b) observer is moving. In one second observer moves through a distance $OO' = v_0$. Since observer is moving away from waves emitted by S, the number of waves received per second now is less. Obviously, the observer will not receive waves contained in distance OO'. The apparent frequency n_3 is

$$n_3 = n - \frac{OO'}{\lambda} = n - \frac{v_0}{\lambda}$$

$$= n - \frac{v_0}{(c/n)} = n\left[1 - \frac{v_0}{c}\right] \quad ...(iii)$$

Obviously, $n_3 < n$. In case the *observer moves towards source,* the apparent frequency n_4 is obtained by replacing v_0 by $-v_0$ in Eqn (iii). Hence,

$$n_4 = n\left[1 + \frac{v_0}{c}\right] \quad ...(iv)$$

For speed of source or observer very small as compard to speed of light Eqns (i) and (ii) reduce to Eqns (iv) and (iii) respectively. For $v_s < c$; Eqn (i) is rewritten as

$$n_1 = n\left[1 - \frac{v_s}{c}\right]^{-1} = n\left[1 + \frac{v_s}{c}\right]$$

This is same as Eqn (iv). For speed small as compared to speed of light; the change in frequency Δn is

$$\Delta n = \pm \frac{v_s}{c} n \quad ...(v)$$

Since $\lambda = c/n$ or $n = c/\lambda$

$$\Delta n = -\frac{c}{\lambda^2}\Delta\lambda \quad ....(vi)$$

From Eqn (v) and (vi)

$$\frac{-c}{\lambda^2}\Delta\lambda = \pm\frac{n}{c}v_s \text{ or } -\frac{c}{\lambda^2}\Delta\lambda = \pm\frac{v_s}{c}\left(\frac{c}{\lambda}\right)$$

When source moves away from observer v_s is –ve hence $\Delta\lambda$ is +ve. In other words *apparent wavelength is more than* the *actual wavelength.* The spectrum of the source shift towards the red end. This is known as the *"red-shift"*. However if source moves towards observer, v_s is –ve and $\Delta\lambda$ is –ve. This means the apparent wavelength is less than the actual one. The spectrum of source shifts towards the violet end of spectrum. This shift is known as *blue or violet shift.*

SOLVED NUMERICAL PROBLEMS ON UNIT – VIII

Example 1. *Two slits in Young's double slit experiment are separated by a distance of 0.03 mm. An interference pattern is produced on a screen 1.5 m away. The 4th bright fring is at a distance of 1 cm from the central maximum. Calculate the wavelength of light used.* **[CBSE 1995]**

Solution : The distance of 4th bright fringe from the central fringe is 4β, where β is the fringe width. Given,

$$4\beta = 1 \text{ cm} = 10^{-2} \text{ m}$$

or

$$\beta = \frac{1}{4} \times 10^{-2} \text{ m}$$

Also, $d = 0.03 \text{ mm} = 3 \times 10^{-5}$ m, $D = 1.5$ m

Now,

$$\beta = \frac{\lambda D}{d} \text{ or } \lambda = \frac{\beta d}{D}$$

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$$\therefore \quad \lambda = \frac{0.25 \times 10^{-2} \times 3 \times 10^{-3}}{1.5} \text{ m} = 0.5 \times 10^{-7} \text{ m}$$

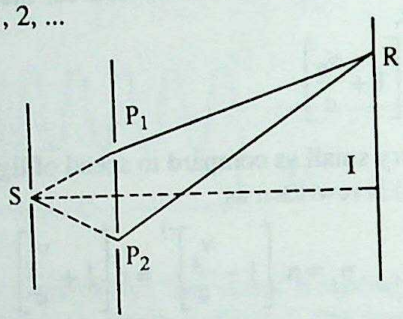
$$= \mathbf{500\ \text{Å}}.$$

Example 2. *A slit S, is illuminated by a monochromatic source of light to give two coherent sources P_1 and P_2. These give bright and dark bands on a screen. At a point R on the screen, there is a dark fringe. What relationship must be between the lengths P_1R and P_2R ?* **(CBSE 1993 Compttl.)**

Solution : Since there is a dark fringe at R, the waves from P_1 and P_2 must reach there out of phase. This happens when the path difference is an odd integral multiple of $\pi/2$.

Hence, $(P_2R - P_1R = (2n + 1)\,\lambda/2;$

$n = 0, 1, 2, \ldots$



Thus, we can have

$P_2R - P_1R = \lambda/2,\ 3\lambda/2,\ 5\lambda/2$..... etc.

Example 3. *In a Young's double slit experiment, the slits are separated by 0.24 mm. The screen is 1.2m away from the slits. The fringe width is 0.3 cm. Calculate the wavelength of light used in the experiment*

(C.B.S.E.1993 Compttl.)

Solution : We know that the fringe width β is given by $\beta = \frac{\lambda D}{d}$

Here $\beta = 0.3 \text{ cm} = 0.3 \times 10^{-2}$ m, $D = 1.2$ m

and $d = 0.24 \text{ mm} = 0.24 \times 10^{-3}$ m

$$\therefore \ \lambda = \frac{\beta d}{D} = \frac{0.3 \times 10^{-2} \times 0.24 \times 10^{-3}}{1.2} \text{ m} = \frac{72 \times 10^{-8}}{1.2} \text{ m} = 60 \times 10^{-8} \text{ m} = \mathbf{6000\ \text{Å}}.$$

Example 4. *In Young's experiment the slits are 1.5m from the screen. The width of the fringes observed with light of wavelength 6000 Å is 1 mm. What is the separation of the slits?* **(CBSE 1991)**

Solution. The fringe width $\beta = \lambda D/d$. Given,

$\beta = 1 \text{ mm} = 10^{-3}$; $D = 1.5$ m, $\lambda = 6000\ \text{Å} = 6 \times 10^{-7}$ m

$$\therefore \quad d = \lambda D/\beta = \frac{6 \times 10^{-7} \times 1.5}{10^{-3}} \text{ m} = 9 \times 10^{-4} \text{ m} = \mathbf{0.9\ mm}.$$

Example 5. *In Young's double slit experiment the slits are separated by 0.3 mm and screen is placed 1.2 m away. The distance between the central bright fringe and the fifth bright fringe is 1.5 cm. What is λ?*

Solution : The distance between the central and the 5th bright fringe is $5\beta = 1.5$ cm.

Therefore $\beta = 0.3 \text{ cm} = 3 \times 10^{-3}$ m. Also $\beta = \lambda\, D/d$. Given,

$d = 0.3 \text{ mm} = 3 \times 10^{-4}$ m; $D = 1.5$ m

$$\therefore \ \lambda = \beta\, d/D = 3 \times 10^{-3} \times 3 \times 10^{-4}/1.5 = 6 \times 10^{-7} \text{ m} = \mathbf{600\ mm}.$$

Example 6. *In Young's double slit experiment the distance between the central bright fringe and the third dark fringe is 1 cm. The distance of screen from interfering sources is 80 cm. If λ = 600 nm, what is the separation between the two interfering sources?*

Solution : The distance between the central bright fringe and the 3rd dark fringe is $5\,\beta\,/\,2$, where β is the fringe width. Given,

$5\beta/2 = 1$ cm or $\beta = 0.4 \text{ cm} = 4 \times 10^{-3}$ m

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$\lambda = 600\ nm = 6 \times 10^{-7}\ m$; $D = 80\ cm = 0.8\ m$

$\therefore \quad \beta = \lambda D/d$ or $d = \lambda D/\beta$

or $d = 6 \times 10^{-7} \times 0.8 / 4 \times 10^{-5} = \mathbf{12 \times 10^{-3}\ m}$.

Example 7. *Sodium light λ = 5890 Å is incident on a Young's double slit experiment. The separation between the two slits is 2.0 mm. If screen is placed at a distance of 4 mm from the slits, locate the position of 10th bright fringe on the screen.*

Solution. The distance x_n of the nth bright fringe from the central fringe, in Young's experiment is

$$x_n = n\lambda D/d$$

Given, $n = 10$; $\lambda = 589 \times 10^{-9}$ m; $D = 4$ m; $d = 2 \times 10^{-3}$ m

$$\therefore \quad x_{10} = \frac{10 \times 589 \times 10^{-9} \times 4}{2 \times 10^{-3}}\ m = 1178 \times 10^{-5}\ m$$

$$= 0.01178\ m = \mathbf{1.178\ cm}.$$

Example 8. *Find the ratio of intensities of two points x and y on a screen in a Young's double slit experiment where waves from S_1 and S_2 have path difference of (i) 0 and (ii) $\lambda/4$.*

Solution : We have : phase difference $= \frac{2\pi}{\lambda} \times$ path difference.

Hence, the phase differences at x and y are 0 and $\pi/2$ respectively.

The resultant amplitude A at a point, where the phase difference is θ, is given by

$$A^2 = a^2 + a^2 + 2a.a.\cos\theta = 2a^2(1 + \cos\theta)$$

(Here a is the common amplitude of the disturbance due to either of the coherent sources.)

$\therefore$ At point x, $A_x^2 = I_x = 2a^2(1 + \cos 0°) = 4a^2$ and

At point y, $A_y^2 = I_y = 2a^2(1 + \cos 90°) = 2a^2$

$\therefore I_x/I_y = 4/2 = \mathbf{2 : 1}$

Example 9. *In Young's double slit experiment what is the intensity at a point on screen where the two waves arrive having a phase difference of (i) 60° (ii) 90° and (iii) 120°?*

Solution : Let I_0 be intensity of either of the interfering sources, the intensity I at a point P is

$$I = 4I_0 \cos^2(\delta/2)$$

where δ is the phase difference at P between the two disturbances.

(i) $\delta = 60°$, $\therefore \quad I = 4I_0 \cos^2(30°) = 4I_0(\sqrt{3}/2)^2 = 3I_0$

(ii) $\delta = 90°$; $I = 4I_0 \cos^2(45°) = 4I_0\left(\frac{1}{\sqrt{2}}\right)^2 = 2I_0$

(iii) $\delta = 120°$; $I = 4I_0 \cos^2(60°) = 4I_0\left(\frac{1}{2}\right)^2 = I_0$.

Example 10. *Two coherent sources have intensities in the ratio of 81:1. What is the ratio of maximum intensity to the minimum intensity in the fringe system?*

Solution : Let I_1 and I_2 denote the intensity of the two sources, a_1 and a_2 stand for the amplitude of light from S_1 and S_2. Now,

$$\frac{I_1}{I_2} = \frac{a_1^2}{a_2^2} = \frac{81}{1} \text{ or } \frac{a_1}{a_2} = \frac{9}{1}$$

We know, $\frac{I_{max}}{I_{min}} = \left(\frac{a_1 + a_2}{a_1 - a_2}\right)^2 = \left(\frac{9+1}{9-1}\right)^2 = \left(\frac{10}{8}\right)^2$

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$\therefore I_{max} : I_{min} = 25 : 16.$

Example 11. *In Young's double slit experiment $I_{max} : I_{min} = 25 : 4$. What is the ratio of intensity of the two interfering sources?*

Solution : Let a_1 and a_2 be the amplitude of disturbance from the two sources. Then,

$$\frac{I_{max}}{I_{min}} = \left(\frac{a_1 + a_2}{a_1 \sim a_2}\right)^2 = \frac{25}{4} \quad \text{or} \quad \frac{a_1 + a_2}{a_1 - a_2} = \frac{5}{2} \quad \therefore \quad \frac{a_1}{a_2} = \frac{7}{3}$$

Obviously,
$$\frac{I_1}{I_2} = \left(\frac{a_1}{a_2}\right)^2 = \left(\frac{7}{3}\right)^2 = \frac{49}{9}$$

$\therefore I_1 : I_2 = 49 : 9.$

Example 12. *The width of the two slits in Young's double slit experiment are in the ratio 4:1. What is I_{max}/I_{min}?*

Solution : The intensity of light from the two slits S_1 and S_2 in Young's experiment, is directly proportional to the width of slits. Therefore, $I_1/I_2 = 4/1$. Let a_1 and a_2 be the amplitude of light from S_1 and S_2 respectively.

$$\frac{I_1}{I_2} = \frac{a_1^2}{a_2^2} = \frac{4}{1} \text{ or } \frac{a_1}{a_2} = \frac{2}{1}$$

Also
$$\frac{I_{max}}{I_{min}} = \left(\frac{a_1 + a_2}{a_1 \sim a_2}\right)^2 = \left(\frac{2+1}{2-1}\right)^2 = \frac{9}{1}.$$

Example 13. *State the conditions for obtaining sustained interference of light from different sources. The ratio of intensities of maxima and minima in an interference pattern is found to be 25:9; Calculate the ratio of light intensities of the sources producing this pattern.* **(CBSE 1999)**

Solution: See theoretical section for 1st part.

We have,
$$\frac{I_{max.}}{I_{min.}} = \frac{25}{9} = \frac{\left(\frac{a_1}{a_2} + 1\right)^2}{\left(\frac{a_1}{a_2} - 1\right)^2}$$

$$\Rightarrow \quad \frac{\frac{a_1}{a_2} + 1}{\frac{a_1}{a_2} - 1} = \frac{5}{3} \Rightarrow 3a_1 + 3a_2 = 5a_1 - 5a_2$$

$$\Rightarrow 8a_2 = 2a_1 \Rightarrow \frac{a_1}{a_2} = \frac{4}{1}$$

$$\therefore \quad \frac{I_1}{I_2} = \frac{a_1^2}{a_2^2} = \frac{16}{1} = 16 : 1.$$

Example 14. *Determine the angular separation between the central maximum and first order minimum of the diffraction pattern due to a single slit of width 0.25 mm when light of wavelength 5890 Å is incident on it normally.* **(CBSE 1993)**

Solution : The angular separation 'θ' between the central maxima and the first order minimum is given by

$$\sin\theta = \lambda/d = \frac{5890 \times 10^{-10}}{0.25 \times 10^{-3}} = 23560 \times 10^{-7} = 0.0023560$$

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Since, sin θ is very small, we can take sin θ = θ. Hence

θ = 0.0023560 radian = 0.135° ≅ **8.1 minute.**

Example 15. *Assuming the diameter of the eye pupil to be 2.0 mm, calculate the smallest angular separation at which two point objects can be distinctly seen when viewed in light of wavelength 6000 Å.*

(CBSE, 1991)

Solution : The pupil of the eye acts as the aperture at which diffraction of light takes place. The objects are just resolved if the principal maximum due to one coincides with the position of the first minimum in the diffraction pattern. In other words the angular separation between objects just equals half the angular width of the central maximum in the diffraction pattern. Therefore, $\theta = \lambda/d$

Given $\lambda = 6000\ Å = 6 \times 10^{-7}$ m; $d = 2$ mm $= 2 \times 10^{-3}$ m

$\therefore \theta = 6 \times 10^{-7}/2 \times 10^{-3} = \mathbf{3 \times 10^{-4}}$ **radian.**

Example 16. *Red light of λ = 6500 Å from a distant source falls on a slit of 0.5 mm width. What is the distance between the two dark bands on each side of the central bright band of diffraction pattern observed on screen placed 1.8 m from the slit?* **(CBSE 1990)**

Solution : Fig. below shows the set up. O is the central bright fringe. D_1 and D'_1 is the first dark fringe on either side of central maxima. Obviously, $BD_1 - AD_1 = \lambda$, and $\theta = \lambda / d$

Let the distance $OD_1 = x = OD'_1$

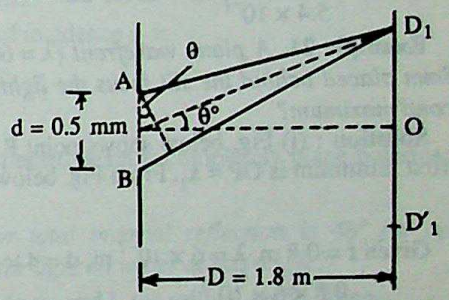
Also, $OD_1 = D \times \theta = \dfrac{\lambda D}{d}$

Given $\lambda = 6.5 \times 10^{-7}$ m; D = 1.8 m, $d = 5 \times 10^{-4}$ m

$$\therefore \quad x = OD_1 = \frac{6.5 \times 10^{-7} \times 1.8}{5 \times 10^{-4}}$$

$$= 2.34 \times 10^{-3} \text{ m} = 2.34 \text{ mm}$$

The distance between D_1 and $D'_1 = 2x =$ **4.68 mm.**



Example 17. *Calculate the distance a beam of light of wavelength 500 nm can travel without any significant broadening. The diffracting aperture is 3 mm wide.* **(CBSE 1990)**

Solution : The angular width θ of the diffraction maximum is λ/d. Up to distance D, the linear separation between the diffracted rays is equal or less than size of aperture and the broadening due to diffraction is insignificant. Therefore,

$D\theta = d$ or $D\lambda/d = d$

$\therefore D = d^2/\lambda$

Given $\lambda = 500$ nm $= 5 \times 10^{-7}$ m; $d = 3$ mm $= 3 \times 10^{-3}$ m

$$\therefore D = \frac{(3 \times 10^{-3})^2}{5 \times 10^{-7}} = \mathbf{18\ m},$$

Example 18. *A slit of width d is illuminated by light of wavelength 6500 Å. For what values of d will the*
(i) First minimum fall at an angle of diffraction of 30°?
(ii) First maximum fall at an angle of diffraction of 30°? **(CBSE 1998)**

Solution: $\lambda = 6500\ Å = 6500 \times 10^{-10}$ m

(i) We have, $d \sin\theta = \lambda$

$$\Rightarrow d = \frac{\lambda}{\sin\theta} = \frac{6500 \times 10^{-10}}{\sin 30^\circ} = 1.3 \times 10^{-6} \text{ m}$$

(ii) We have, $d \sin\theta = \frac{3}{2}\lambda$

$$\Rightarrow d = \frac{3}{2} \cdot \frac{\lambda}{\sin\theta} = \frac{3}{2} \times \frac{6500 \times 10^{-10}}{\sin 30^\circ} = \mathbf{1.95 \times 10^{-6}\ m.}$$

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Example 19. *What is the minimum aperture of the objective of a telescope which will enable two neigbouring stars to be seen separately? The angle subtended by the two stars at the objective of telescope is 3×10^{-6} radian. $\lambda = 5460$ Å.*

Solution : The two stars will just appear separate if the principal maximum due to one coincides with the first minimum of the other, in diffraction pattern. In other words the half angular width of diffraction maximum is just equal to angle subtended by the stars at the objective of telescope. If d is aperture of telescope objective then, $\theta = \lambda/d$

or $3 \times 10^{-6} = 5.46 \times 10^{-7}/d$ or $d = 5.46 \times 10^{-7}/3 \times 10^{-6}$ **= 0.182 m.**

Example 20. *Calculate the distance a beam of light of wavelength 540 cm can travel without significant broading. The size of the aperture is 4 mm.* **(CBSE 1990)**

Solution : Angular width of the principal maxima, due to diffraction at an aperture of size d is $\theta = \lambda/d$.

Let D be the distance the beam travels without significant broadening. Then $D\theta = d$

$$\therefore D = d/\theta = \frac{d^2}{\lambda}$$

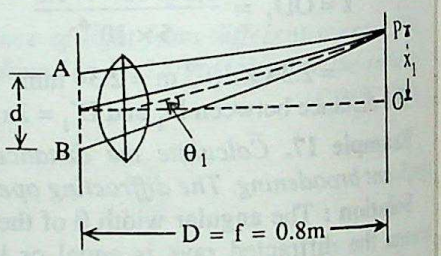
Given $d = 4 \text{ mm} = 4 \times 10^{-3}$ m, $\lambda = 540 \text{ mm} = 5.4 \times 10^{-7}$ m

$$\therefore D = \frac{(4 \times 10^{-3})^2}{5.4 \times 10^{-7}} \text{ m} = \mathbf{29.63 \text{ m}}.$$

Example 21. *A plane wavefront ($\lambda = 600$ nm) falls on a slit 0.4 mm wide. A convex lens of focal length 0.8mm placed behind the slit focus the light on a screen. What is linear diameter of (i) first minimum and (ii) second maximum?*

Solution : (i) Fig. below shows point P is the first minimum after central maximum. The linear dimension of first minimum is $OP = x_1$. From Fig. below.

$$x_1 = f\theta = f\lambda/d$$



Given $f = 0.8$ m, $\lambda = 6 \times 10^{-7}$ m, $d = 4 \times 10^{-4}$ m

$$\therefore x_1 = \frac{0.8 \times 6 \times 10^{-7}}{4 \times 10^{-4}} \text{ m} = 1.2 \times 10^{-3} \text{ m} = \mathbf{1.22 \text{ mm}}.$$

(ii) For second maximum, the angular spread $\theta_2 = 3\lambda/d$.

The linear dimension x_2 of second maximum is

$$x_2 = f\theta_2 = \frac{3f\lambda}{2d} = \frac{3 \times 0.8 \times 6 \times 10^{-7}}{2 \times 4 \times 10^{-4}} \text{ m} = \mathbf{1.8 \times 10^{-3} \text{ m} = 1.8 \text{ mm}}.$$

Example 25. *A beam of unpolarized light is sent through two polarizing sheets placed one on top of the other. What must be the angle between the polarising directions of the sheets if the intensity of the transmitted light is one-third the intensity of the incident light?*

Solution : Let I be the incident light intensity. The intensity of light passing through the first sheet is I/2. After passing through the second sheet, this intensity becomes. (1/2) cos θ, where θ is the angle between the polarising directions of the two sheets. We want θ to be such that

$$\left(\frac{1}{2}\right)\cos^2\theta = \frac{1}{3} \text{ or } \cos^2\theta = \frac{2}{3}$$

$$\therefore \quad \cos\theta = \sqrt{2/3} = 0.8165$$

$$\theta = \cos^{-1}(0.8165) = \mathbf{35.30°}.$$

Example 24. *The polarising sheets are placed with their planes parallel, so that light intensity transmitted is maximum. Through what angle either sheet be turned so that intensity drop to half the maximum value?*

Solution : According to *Malus* law, the intensity I of transmitted light from an analyser is $I = I_0 \cos^2\delta$ where δ is angle between analyser and polariser. Given $I = I_0/2$. Therefore,

$$I_0/2 = I_0 \cos^2\delta \text{ or } \cos^2\delta = 1/2$$

$$\therefore \quad \cos\delta = 1/\sqrt{2} \quad \text{or} \quad \delta = \pi/4 \text{ or } 135°.$$

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Example 25. *(i) Give the ratio of velocities of light rays of wavelengths 4000 Å and 8000 Å in vacuum.* **(CBSE 1997)**

(ii) The polarising, angle of a medium is 60°. What is the refractive index of the medium? **(CBSE 1999, 2000)**

(iii) What is the polarising angle of a medium of refractive index $\sqrt{3}$ **(CBSE 1999)**

(iv) The refractive index of the denser media is 1.732. Calculate:

(a) the polarising angle of the medium, (b) the anagle of refraction. **(CBSE 1999)**

Solution: (i) Light waves of all waveslengths travel in *vacuum* with a speed of 3×10^8 m/s. Hence, the required ratio is 1 : 1.

(ii) We have $\mu = \tan i_p = \tan 60^\circ = \sqrt{3}$.

(iii) We wave $\mu = \tan i_p \Rightarrow \sqrt{3} = \tan i_p \Rightarrow i_p = 60^\circ$.

(iv) (a) We have $\mu = \tan i_p \Rightarrow 1.732 = \tan i_p \Rightarrow i_p = 60^\circ$.

(b) Angle of refraction $= 90^\circ - i_p = 30^\circ$.

Example 26. *A glass plate (μ = 1.5) is used as a polariser. Obtain the polarising angle of incidence. What is the angle of refraction when the reflected light is plane polarised?*

Solution : According to Brewster's law the polarising angle of incidence i_p is

$$\mu = \tan i_p \text{ or } 1.5 = \tan i_p$$

$$\therefore \quad i_p = \tan^{-1}(1.5) = \mathbf{56.3^\circ}.$$

When light is incident at polarising angle of incidence the reflected beam is completely plane polarised and if r is angle of refraction $i_p + r = 90^\circ$; $r = 90 - 56.3 = \mathbf{33.7^\circ}$.

Example 27. *The critical angle of incidence of water for total internal reflection is 48° for certain wavelength. What is the polarising angle and angle of refraction for light on water at this angle?*

Solution : Let μ be the refractive index of water with respect to air and i_c the critical angle. Then,

$\mu = 1 / \sin i_c = 1 / \sin 48^\circ = 1 / 0.7431 = 1.345$

Let i_p be the polarising angle of incidence. From Brewster's law, $\tan i_p = \mu = 1.345$

or $$i_p = \tan^{-1}(1.345) = 53^\circ 22'$$

At polarising angle of incidence, if r is angle of refraction, $i_p + r = \frac{\pi}{2}$

$\therefore r = 90 - 53^\circ 22' = \mathbf{36^\circ 38}$.

Example 28. *In a star the hydrogen emits waves of λ = 650 nm. The "red-shift" in the wavelength is 15 Å. What is the speed of the star with respect to earth?*

Solution : Since a "red-shift" is observed, the star is moving away from the earth. Let v be the speed of star. Then apparent wavelength $\lambda = \lambda [1 + v/c]$, where c is speed of light. Obviously, $\Delta\lambda = \lambda - \lambda = \lambda v/c$

Given $\Delta\lambda = 15$ Å $= 15 \times 10^{-10}$ m; $\lambda = 6.5 \times 10^{-7}$; $c = 3 \times 10^8$ ms^{-1}

$$\therefore v = (\Delta\lambda)\frac{c}{\lambda} = \frac{15 \times 10^{-10} \times 3 \times 10^8}{6.5 \times 10^{-7}} = \mathbf{6.923 \times 10^5 \text{ ms}^{-1}}.$$

Example 31. *What is Doppler's effect in light? The spectral line for a given element in light received from a distant star is shifted towards conger wavelength by 0.025%. Calculate the velocity of star in line of right.* **(CBSE 1997)**

Solution: See theoretical section for 1st part.

We have, $\frac{\Delta\lambda}{\lambda} = 0.025\% = \frac{0.025}{100}$, $c = 3 \times 10^8$ m/sec.

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c} \Rightarrow v = \frac{\Delta\lambda}{\lambda} \cdot c = \frac{0.025}{100} \times 3 \times 10^8 = \mathbf{7.5 \times 10^4 \text{ m/sec.}}$$

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UNIT - IX

RAY OPTICS AND OPTICAL INSTRUMENTS

CBSE SYLLABUS CONTENTS

Sources of light, luminous intensity, luminous flux, illuminance. Photometry — Bunsen's grease photometer. Reflection of light — curved mirrors, mirror formulae. Refraction of light, total internal reflection, spherical lenses, lens formulae, lens maker's formula, magnification. Refraction and dispersion of light due to a prism, spectrometer — its use for determination of refractive index of the material of a prism. Spectra — absorption and emission, scattering of light in atmosphere, primary rainbow. Optical instruments — simple and compound microscopes, refracting (Astronomical) and reflecting (Newtonian) telescopes – resolving power and magnifying power.

No. of periods allotted : 17 out of 168

No. of marks allotted: 7 out of 70.

BASIC FACTS AND FORMULAE

1. Light is that radiant part of energy which effects human retina and produces the sensation of vision. According to Newton, 'light has particle nature'. Huygen, however, believed in the wave nature of light. We now believe in the dual nature of radiation.

2. Sources of light : Any object that emits visible radiation is a source of light. Sun is most important natural source of light. Electric bulb, fluorescent tube, candel are man made sources of light. Sources of light can be divided into three categories :

(i) Thermal, (ii) gas discharge and (iii) luminiscent.

3. The total light radiated per unit time in all directions is known as the *total luminous flux*. The energy emitted per second in *visible region* is the luminous flux. Its unit is lumen.

4. The luminous intensity (I) of a given source is the luminous flux per unit solid angle in that direction. It is also known as illuminating power. S.I. units of luminous intensity is candela.

5. The illuminance or intensity of illumination is the amount of light energy falling per unit area, when the area is held perpendicular to the direction of light. Illuminance, due to a point source, is inversely proportional to the square of distance of point from the source. SI units of illumenance is *lux* or lumen/m^2.

6. Photometry is the branch of physics involved measurement of light by visual comparison. The instrument used for this purpose is known as a photometer. Usually, photometer compares the luminous intensities of two sources by matching the brightness produced by them. According to principle of photometery,

$$\frac{E_1}{E_2} = \frac{r_1^2}{r_2^2}$$

E_1 and E_2 denote the intensities of the two sources. r_1 and r_2 are the respective distances of the two sources from an area equally illuminated by either source.

7. Reflection of light

Whenever light meets an obstacle in its path and a part of it (light), is thrown back into the same medium, light is said to have undergone reflection.

The ray of light is the path along which light travels in a medium. A group of rays constitutes a beam of light. The beam is parallel, convergent or divergent depending on whether rays constituting the beam are parallel, meet at a point or appear to meet at a point. A very narrow beam of light is referred to as a pencil of light.

Whenever light meets a boundary separating two media, a part of it is (i) thrown back into first medium.

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(ii) passed on to the second medium and (iii) absorbed. In other words, in general, a ray of light undergoes (i) reflection, (ii) refraction and (iii) absorption at a boundary separating two media.

8. Some Useful Terms

A mirror that is a part of a spherical surface is known as spherical mirror. There are two types of spherical mirrors : (i) *concave* and (ii) *convex.*

For spherical mirrors the following terms are found convenient to work with : (i) centre of curvature is the centre of the sphere of which mirror is a part, (ii) radius of curvature of the mirror is the radius of the sphere of which mirror is a part, (iii) the middle point of the mirror is the *pole*, (iv) the line joining the centre of curvature and pole is the principal axis.

9. Reflection at a Curved Mirror

For a point object placed on the principal axis of a spherical mirror, in general, there is *no* single, *well defined point image, i.e.,* different rays from the point object after reflection do not meet at a single point on the principal axis. However, if we restrict ourselves to *paraxial rays,*. (i.e., rays making small angles with principal axis) there *is a point image for a point object.*

10 . The Coordinate Convention of Signs

The coordinate system for any optical problem is chosen in the following manner : (i) Incident rays are always drawn as proceeding from left to right, (ii) the pole or optical centre of the system is chosen as the origin of coordinate system, (iii) the distance, from the origin, same as that of incident rays, is the direction of the distances along principal axis, (iv) distances perpendicular to principal axis are positive for points lying above it (the principal axis).

The object, the image position are denoted by symbols u, v respectively. *Position* of an object or image is the respective distances to which a plus or minus sign is prefixed in accordance with the coordinate convention of signs.

11. The Mirror Formula

In terms of u,v and *R*, the relation between the object, the image position and radius of curvature for *both* concave as well convex mirror is,

$$\frac{1}{v}+\frac{1}{u}=\frac{2}{R}$$

or

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}.$$

On using above relation all known quantities are substituted with their appropriate signs. The sign as well as magnitude of the unknown parameters is worked out from the above relation.

In coordinate convention, u *is always negative for a real object.* A positive sign with u *means a virtual object.* In *reflection,* v *negative indicates a real image,* whereas v is positive *for a virtual image.* The radius of curvature and focal length is negative *for a concave mirror and positive for a convex mirror.*

12. The Focus and the Focal Length

An incident ray parallel to the principal axis after reflection meets or appears to meet the principal axis at a point. This point is known as the *focus.* The *position of focus* gives the focal length f. For spherical mirrors

$$f = R/2.$$

13. Image of an Object of Finite Size and Magnification

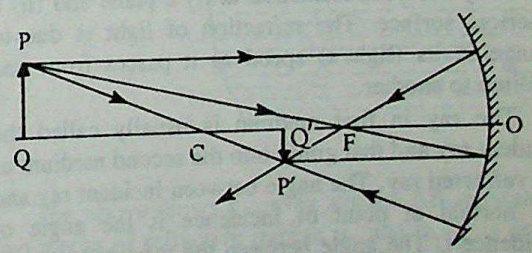
For an *object of finite size* placed on principal axis, the image is located using the following important rays:

(i) An incident ray parallel to the principal axis, passes through focus after reflection.

(ii) An incident ray passing through focus, proceeds as a ray parallel to the principal axis, after reflection.

(iii) An incident ray passing through the centre of curvature retraces its path on reflection.

Fig. below shows the formation of image of an object PQ by a concave mirror, using three rays



The ratio of the size of the image and object is known as magnification, i.e.,

$$m = \frac{\text{Size of image}}{\text{Size of object}}$$

m is a quantity having a plus, minus sign. The *plus* sign *of m indicates erect image,* whereas a *negative sign* before *m* indicates *inverted* image. Some useful expressions for magnification are :

$$m = -\frac{v}{u} = \frac{R-v}{R-u} = \frac{f-v}{f}$$

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14. The following table summarises the characteristics of the image formed by a *concave mirror* as an object is moved from infinity towards the mirror.

Object position		Image position	Nature
(i)	At infinity.	At focus.	Real, inverted, smaller in size.
(ii)	Between ∞ and centre of curvature.	Between centre of curvature and focus.	Real, inverted, smaller in size.
(iii)	At centre of curvature.	At centre of curvature.	Real, inverted, same size.
(iv)	Between centre of curvature and focus.	Beyond centre of curvature.	Real, inverted, larger in size.
(v)	At focus.	At infinity.	—
(vi)	Between focus and pole.	Behind the mirror.	Virtual, erect and enlarged.

The image of a real object, formed by a *convex mirror* is always *virtual.*

For mirrors of large aperture, the rays undergoing reflection at the edge and near the middle do not meet at a single point. The different rays are reflected on to a surface known as the *caustic.*

A *paraboloidal mirror* focuses all rays parallel to the principal axis at a single point.

15. Refraction of Light

The bending of light from its straight line path, as it passes from one medium to another, is *refraction.* We study in detail refraction at (i) a plane and (ii) a spherical surface. The refraction of light is due to change in its (light's) speed as it passes from one medium to another.

The ray in first medium is usually called the incident ray and that going into the second medium as the refracted ray. The angle between incident ray and the normal at point of incidence is the angle of incidence i. The angle between the refracted ray and the normal at point of incidence is the angle of refraction r.

In passing from a denser to a rarer medium, the ray bents away from the normal and *vice-versa.*

16. Snell's Law

According to Snell's law of refraction :

(i) The incident ray, the refrected ray and normal at point of incidence lie in the same plane;

and (ii) $\frac{\sin i}{\sin r} = \text{constant}$ or $\mu_1 \sin i = \mu_2 \sin r$.

where μ_1 and μ_2 denote the refractive index of the object and image space.

17. Absolute and Relative Refractive Index

The absolute refractive index μ of any medium is the ratio of speed of light in vacuum to that in the medium.

$$\mu = \frac{\text{Speed of light in vacuum}}{\text{Speed of light in medium}} = \frac{c}{v}$$

The relative refractive index of medium 2 with respect to medium 1 (i.e., ${}_1\mu^2$) as

$${}_1\mu^2 = \frac{\mu_2}{\mu_1} = \frac{v_1}{v_2}$$

18. The Passage of Light Through a Plane Glass Slab

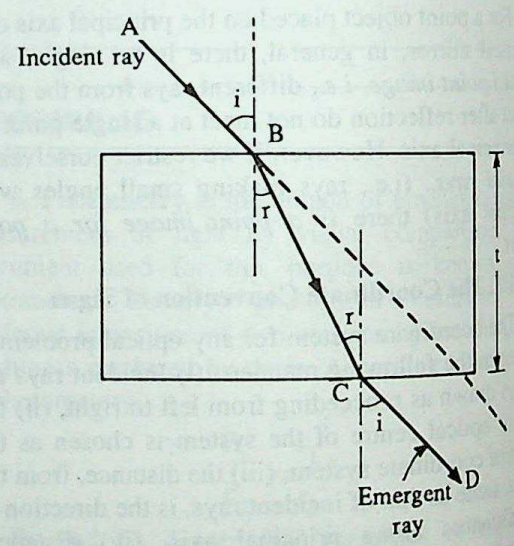

Fig. above shows an incident ray AB on a glass slab of thickness t and refractive index μ. CD is the emergent ray.

On passing through a plane glass slab light does not suffer any deviation, *i.e.,* the incident and emergent rays are parallel. However, emergent ray is displaced with respect to the incident ray. The displacement, Δx, in passing through a glass slab of thickness t and refractive index μ is.

$$\Delta x = t \sin i \left[1 - \frac{\cos i}{(\mu^2 - \sin^2 i)^{1/2}}\right],$$

where i is the angle of incidence. The maximum displacement corresponding to $i = \pi/2$ is equal to the thickness of the slab.

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19. The Real and the Apparent Depth of a Pond

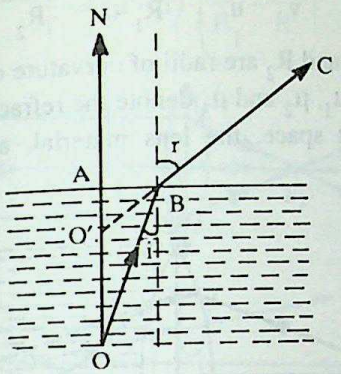


Fig. above shows a point O on the bottom of a tank containing a liquid, say water. OA = real depth. OB is a ray incident at point B. The refracted ray BC bends away from normal. r is the angle of refraction. The refracted ray BC appears to come from point O'. O'A is the apparent depth of pond.

Due to refraction, a pond of water appears shallower than it is, *i.e.*, apparent depth of the pond is less than the real depth. Also,

$$\mu = \frac{\text{Real depth}}{\text{Apparent depth}}$$

20. Total Internal Reflection

When light passes from a denser to a rarer medium it (light) bends away from the normal. For some angle of incidence i_c the angle of refraction is 90°. If angle of incidence $i > i_c$, light is reflected back into the first medium and is said to have undergone *total internal reflection.* This is shown in fig below. Angle i_c is known as the critical angle. If light passes from a medium of refractive index μ_1 to medium of refractive index μ_2 ($\mu_1 > \mu_2$), the critical angle i_c is

$$\mu_1 \sin i_c = \mu_2 \sin \pi/2$$

or $$\sin i_c = \frac{\mu_2}{\mu_1}$$

If light passes from glass ($\mu_2 = \mu$) to air $\mu_1 = 1$, critical angle i_c is $\sin i_c = 1/\mu$.

21. Some Common Examples of Total Internal Reflection

(i) A metallic ball coated with soot suspended in water appears silvery bright. (ii) The sparkling of diamonds is due to total internal reflection. The diamond is so cut that critical angle is quite low (~24°) and light undergoes total internal reflection easily. (iii) The optical illusion met within deserts or in cold countries near sea side is due to total internal reflection. (iv) Totally reflecting prisms are used in the construction of a periscope.

22. Light Pipe or Fibre Optics

Total internal reflection is used in *fibre optics.* The fibre optics basically is a pipe of fibre so designed that light entering it at one end undergoes a large number of total internal reflections and emerges out of the other end without any appreciable change in intensity. Fibre optics is finding increasing use in *micro-surgery.*

23. Refraction at a Spherical Surface

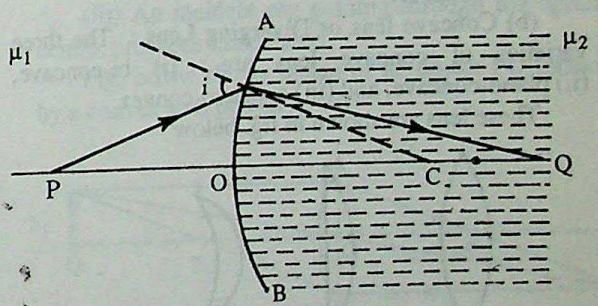
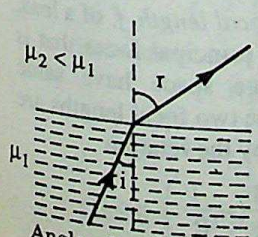
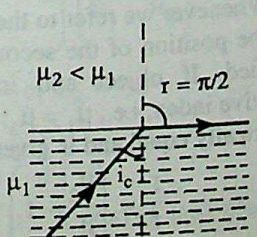


Fig. above shows a convex surface AB separating two media of refractive indices μ_1 and μ_2. P is point object placed on principal axis. Q is the image formed due to refraction, by paraxial rays.

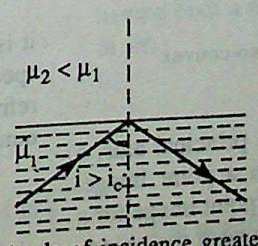
24. For a point object situated on the principal axis of a spherical surface (either convex or concave) separating two media, in general, there is *no single point image* formed in the second medium. However, for *paraxial rays,*



Angle of incidence (i) less than vertical angle



Angle of incidence equal to critical angle



Angle of incidence greater than critical angle

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there is a point image for a point object. The object and image position u and v respectively are related to one another by the relation

$$\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R},$$

where μ_1 and μ_2 stand for the refractive index of the object and image space and R is radius of curvature of the spherical surface.

u, v and *R* are quantities having both magnitude and sign. The sign is prefixed in accordance with the coordinate convention of signs. In refraction, a *negative sign* before u indicates a *real object,* whereas a *positive sign* before u indicates *virtual image.* On the other hand, a *positive sign* before v indicates a *real image*, whereas a *negative sign* indicates a *virtual image*. In using the refraction formula, the known quantities are always substituted with their appropriate signs. The sign as well as magnitude of unknown quantity is obtained by solving the above equation.

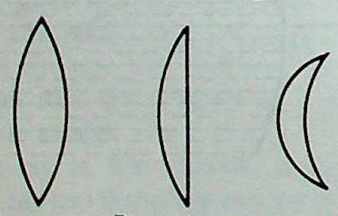
25. Thin Lens

A lens is a transparent refracting medium bound by two spherical surfaces. Lenses are divided into two categories :

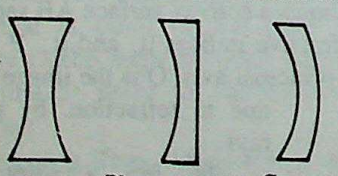
(a) Convex Lens or Converging Lens : The lens may be bi-convex, plano-convex or convexo-concave.

(b) Concave lens or Diverging Lens : The three varieties of concave lens are : (i) bi-concave, (ii) plano-concave, and (iii) concavo-convex.

These lens are shown in fig. below



Bi-convex Plano-convex Convexo-concave



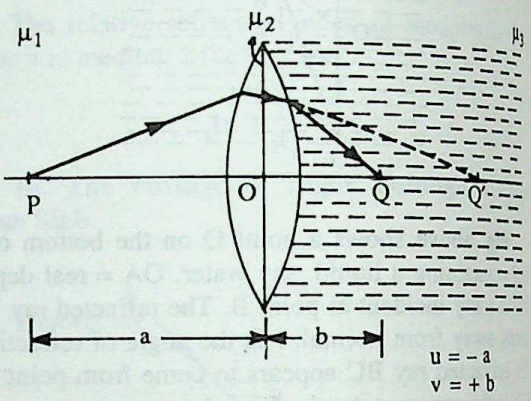
Bi-concave Plano-concave Concavo-convex

26. The Lens Formula

For a point object placed on the principal axis, a thin lens, in general, does not form a point image. However, for *paraxial rays* there is a point image for a point object. The general relation between the object, image positions and the radii of curvature of lens surfaces is

$$\frac{\mu_3}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R_1} + \frac{\mu_3 - \mu_2}{R_2},$$

where R_1 and R_2 are radii of curvature of the two lens surfaces. μ_1, μ_2 and μ_3 denote the refractive indices of the object space, the lens material, and the image space.



27. The Focus, The Focal Length and the Lens Maker's Formula

The point in image space, where an incident beam parallel to the principal axis, meets or appears to meet is the *second principal focus* F_2. The position of F_2 gives the second principal focal length f_2. f_2 is given by the relation

$$\frac{\mu_3}{f_2} = \frac{\mu_2 - \mu_1}{R_1} + \frac{\mu_3 - \mu_2}{R_2}$$

The point F_1 in object space, where from an incident beam diverges or appears to converge to, so that the refracted rays are parallel to the principal axis is the first principal focus. Position of F_1 gives the first principal focal length f_1 which is given by the relation

$$-\frac{\mu_1}{f_1} = \frac{\mu_2 - \mu_1}{R_1} + \frac{\mu_3 - \mu_2}{R_2}$$

In general $f_1 \neq f_2$

Whenever we refer to the *focal length, f,* of a lens, it is the position of the second principal focus that is specified. If object and image space have same refractive index, i.e., $\mu_1 = \mu_3$; the two focal lengths are numerically equal and is given by the relation

$$\frac{1}{f} = \left(\frac{\mu_2}{\mu_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

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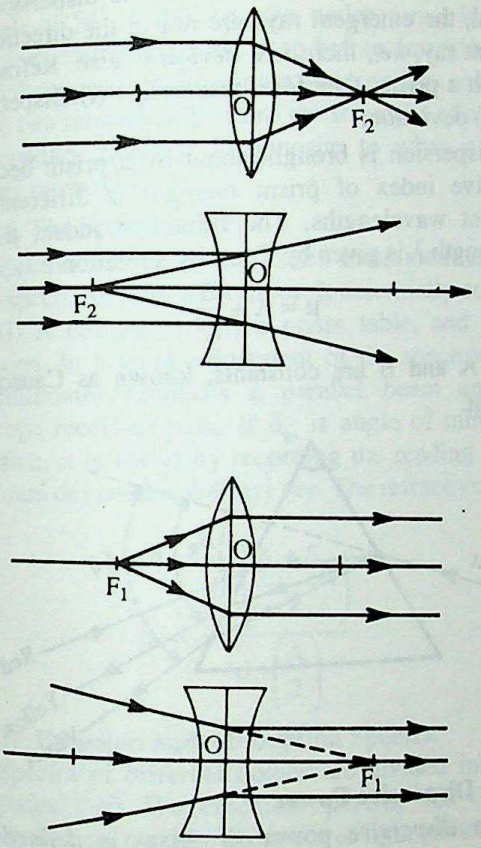
This is known as the *lens maker's formula.* For a lens placed in air $\mu_1 = 1$ and $\mu_2 = \mu$ = refractive index of the lens material, therefore,

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R}\right)$$



If the refractive index of image and object space is same, i.e., $\mu_1 = \mu_2$,

then $|f_1| = |f_2|$

The focal length of a convex lens made of a material of refractive index μ_2 placed in a medium of refractive index μ_1 is

$$\frac{1}{f} = \left(\frac{\mu_2}{\mu_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

For convex lens

$$R_1 = +c;\ R_2 = -d$$

$$\therefore \frac{1}{f} = \left(\frac{\mu_2}{\mu_1} - 1\right)\left(\frac{1}{c} + \frac{1}{d}\right)$$

CASE I : If $\mu_2 > \mu_1$; A convex lens placed in a medium of refractive index less than that of lens material behaves as a *converging lens.*

CASE II : If $\mu_2 < \mu_1$, f is negative. This means that convex lens placed in a medium of refractive index greater than that of the lens material behaves as a *diverging lens.* For example, an air convex lens in a tank of water will behave as a *diverging lens.*

In case of *concave lens,* if $\mu_2 > \mu_1$, f is – ve, whereas f is + ve, if $\mu_2 < \mu_1$.

28. The Power of a Lens

The reciprocal of the focal length of a lens expressed in metre is the power of the lens. The power P is expressed in *diopter.*

$$P\ (\text{in diopter}) = \frac{1}{f\ (\text{in metre})}$$

The power of a convex lens [if $\mu_2 > \mu_1$] is positive, whereas that of a concave lens is negative.

29. Image of an Object of Finite Size and Magnification

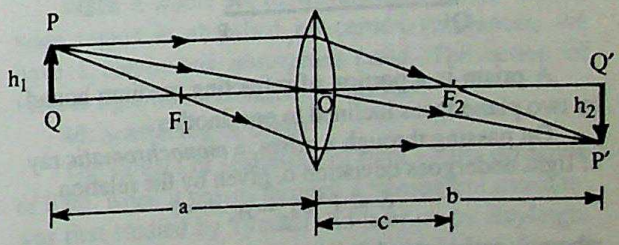
For an object of finite size, the image is located using the following convenient rays :

(i) An incident ray parallel to the principal axis after refraction passes through or appears to pass through the second principal focus F_2.

(ii) An incident ray passing or appearing to pass through the first principal focus F_1 proceeds, after refraction, as a ray parallel to the principal axis.

(iii) An incident ray passing through the optical centre, proceeds undeviated.

Fig. below shows image of an object PQ formed by a convex lens placed in air.



The magnification m is again defined as the ratio of the size of image to the object. m is a quantity having both a magnitude and a sign. For a lens placed in air,

$$m = \frac{y_2}{y_1} = -\frac{v}{u}$$

$$= \frac{f - v}{f}$$

The *negative sign* before m indicates an *inverted image,* whereas a *positive sign* means an erect image.

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30. The Relative Position of Image and Object

The position, nature and magnification of the image formed by a lens depends on the position of the object. A *convex lens* forms a *real, inverted* image of a real object lying between infinity and focus. If the object lies within the focus, the image formed is *virtual*, erect *and magnified.*

A concave lens always forms a virtual image of a real object.

31. Two Thin Lens in Contact

When two thin lenses of focal length f_1 and f_2 are placed in contact with one another, the equivalent focal length, F, is,

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$$

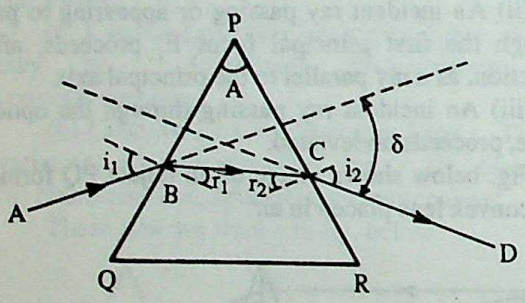
In terms of Power $P = P_1 + P_2$

For *n* thin lenses in contact,

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} + \ldots + \frac{1}{f_n}$$

or $P = P_1 + P_2 + \ldots + P_n$

32. Refraction through a Prism



A prism is a portion of refracting medium bound by two plane faces inclined to one another.

On passing through a prism, a *monochromatic* ray of light undergoes deviation δ, given by the relation

$$\delta = i_1 + i_2 - A,$$

where i_1 and i_2 stand for the angle of incidence on the two faces of the prism and A is the refracting angle of the prism. The angle of deviation is minimum, δ_m, when ray passes symmetrically through the prism. The refractive index μ of the prism is,

$$\mu = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}.$$

For *small-angled* prism, the deviation δ is $\delta = (\mu - 1)\,A$, where A is the refracting angle of the prism.

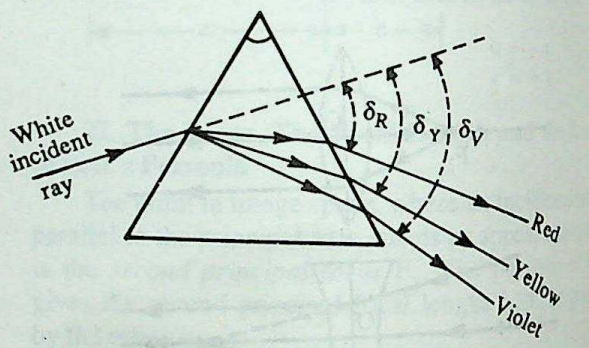
33. Dispersion

When *white* (or *polychromatic*) light passes through a prism, it (light) breakes up into its constituent colours. This is known as dispersion. In general, the emergent rays are not in the direction of incident ray, *i.e.,* there is a *deviation* also. Refraction through a prism, therefore, results in : (i) Dispersion, and (ii) deviation.

Dispersion is brought about by a prism because refractive index of prism material is different for different wavelengths. The refractive index, μ, for wavelength λ is given by Causchy's relation

$$\mu = A + \frac{B}{\lambda^2}$$

where A and B are constants, known as Causchy's constant.



34. Dispersive Power

The *dispersive* power of prism is *defined as dispersion per unit deviation.** It is a constant characteristic of the prism material, for small-angled prism. If δ_v, δ_y and δ_R stand for deviation of violet, yellow and red coloured rays, the dispersive ω is

$$\omega = \frac{\delta_v - \delta_R}{\delta_y} = \frac{\mu_v - \mu_R}{\mu_y - 1}$$

When light undergoes dispersion in prisms of different materials and angles, the ratio of the partial dispersion of any two colours to that of the extreme colours is different. This feature is known as *irrational dispersion.*

35. Rainbow

Rainbow is nature's spectacular display of the phenomenon of dispersion. It is observed when, after the rain, the sun shines. A person standing with his back towards sun observes concentric circular arcs of

* or the dispersive power of a prism is obtained as the ratio of angular dispersion to the mean deviation produced by the prism.

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different colours in the horizon. Rainbow is due to *refraction in water drops*. The rainbow formed due to *one internal reflection* in the water drop is known as the *primary rainbow*. Here, the innermost circular arc is violet in colour subtending a semi-cone angle of 40.8°. The outermost arc is red in colour subtending an angle of 54°. If the sun rays undergo *two internal reflections* inside the water drop before emerging out, the rainbow produced is known as *secondary rainbow*. Due to two internal reflections the sequence of colours in secondary rainbow is opposite to what it is in primary rainbow.

36. The Spectrometer

Spectrometer is a very useful instrument used to study spectra of various sources. It essentially consists of : (i) A collimator, (ii) a prism table, and (iii) a telescope. In normal adjustment of the spectrometer, the collimator produces a parallel beam and the telescope receives them. If δ_m is angle of minimum deviation, it is found by recording the reading of the minimum deviated and direct ray. The refractive index μ is,

$$\mu = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}.$$

37. Emission and Absorption Spectra

Spectra of different bodies are divided into two categories : (i) The *emission spectra,* and (ii) the *absorption spectra.* The spectrum of light emitted by a body is known as the emission spectra. On the other hand, if white light passes through a transparent material and the emergent light is observed, one obtains absorption spectra. Both types of spectra are divided into three categories :

(i) The line emission or absorption spectra.

(ii) The continuous emission or absorption spectra.

(iii) The band emission or absorption spectra.

38. Characteristics of Emission Spectrum

The line emission spectra consist of sharp lines of definite wavelengths with no light in between. In other words, λ is a discrete variable. The lines emitted are characteristic of the element undergoing emission. The emission line spectrum is like the finger prints of an atom. The spectrum of sodium is characterised by two sharp lines of $\lambda = 5890$ Å and 5896 Å; known as the *D-lines*. Very intense lines in mercury spectrum are blue, green, yellow, orange.

The continuous emission spectra contain all possible values of wavelength, i.e., λ is a continuous variable. Its characteristics depend primarily on the temperature of the body. It is not a characteristic of the body undergoing emission. The spectrum from a hot iron, an incandescent bulb or fluorescent tube is a continuous one. For a body, the wavelength corresponding to maximum intensity, moves towards shorter wavelength side as the temperature increases.

The band emission spectra consist of a number of bands separated from one another by dark regions. Close examination shows that each band consists of a large number of lines close by. The band is sharp at one edge and is diffused or fluted at the other. Band spectra are emitted by substances in molecular state.

39. Characteristics of Absorption Spectrum

The line absorption spectrum consists of dark lines against a bright background, when white light passes through atoms in vaporous state. The position of dark lines is exactly same as that of bright lines in emission spectrum. These dark lines are known as *Fraunhoffer's dark lines.* The observation of these dark lines in solar spectrum help us in identifying the elements present in the outer atmosphere around the sun.

The absorption band spectra consisting of dark bands appearing in different parts of the continuous emission spectrum are observed, when white light passes through dilute solution of blood or iodine vapours.

When a whole set of wavelengths spread over a wide region is absorbed by certain substances, we have a *continuous absorption band.* The action of various light filters is based on this fact.

40. Scattering of Light

The subject of scattering of light — the diffusion of light, when it passes through a transparent medium, was first studied by Tyndall and later on by Rayleigh. Unlike Tyndall, who suggested that the blue colour of sky is due to scattering by fine dust particles, etc., Rayleigh suggested that the scattering must be regarded as due to *air molecules* themselves.

Rayleigh also deduced his well-known law of scattering : The percentage intensity of light of wavelength λ present in the scattered light is inversely proportional to the fourth power of wavelength

$$I \propto \frac{1}{\lambda^4}$$

Rayleigh's law can be used to understand such natural phenomenon as 'blue of the sky', red of sky at

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sunrise or sun set, etc. The classical e.m. theory can be used to understand Rayleigh scattering.

41. Microscope or telescope is the optical aid used to see a magnified image of a near by or a distant object respectively.

42. Angular Size of Object and Image

The size of an object or image, as seen by the eye depends on (i) the linear size and (ii) the distance of object or image from the eye. In describing optical instruments we usually use the *angular size* instead of linear size.

43. The Magnifying Power

The angular size of an object, α is the angle subtended by it at the eye, when placed at the distance of distinct vision. For normal human eye, distance of distinct vision is 250 mm.

The angular size of an image, β, is angle subtended by the image at the eye.

The magnifying power or angular magnification, of an optical instrument is the ratio of β and α, *i.e.*,

$$\text{Magnifying power} = M = \beta/\alpha$$

$$= \frac{\text{Angle subtended by the image at eye}}{\text{Angle subtended by the object, when placed at distance of distinct vision}}$$

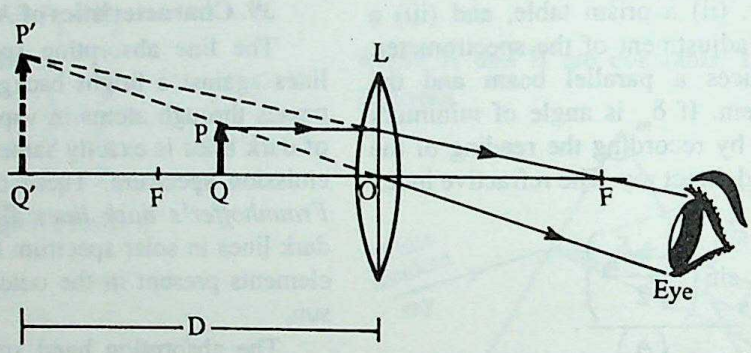
44. The Simple Microscope

A simple microscope is a short length convex lens. The object to be magnified is placed at or within the focus. The final image formed is virtual, erect and magnified. The magnifying power of a simple microscope is,

$$M = 1 + \frac{D}{f}$$

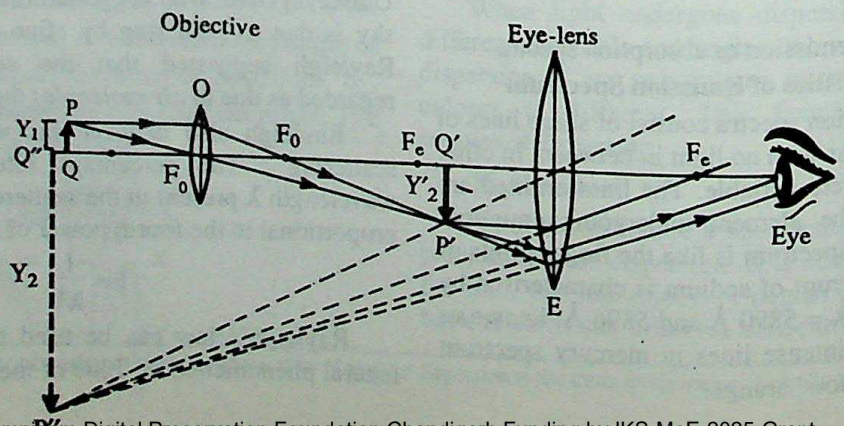
For large values of M, f should be as small as possible.

Fig. below shows the ray diagram showing formation of image by a simple microscope.



45. The Compound Microscope

A compound microscope consists of two converging lens. The object to be magnified is placed just beyond the focus of the objective lens which forms a real, inverted image. This image is either at the focus or within the focus of the eye-lens. The eye-lens acting as a simple microscope forms final image, that is, virtual, erect and magnified. In normal adjustment of microscope the final image is formed at infinity. The magnifying power, M, of a compound microscope is



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$$M = m_o \times m_e,$$

where m_o and m_e denote the linear magnification of the objective and the eye-lens.

Fig. above gives the ray diagram showing formation of image

46. Numerical Aperture and Resolving Power of a Microscope

The purpose of a microscope is not only to enlarge an object but also reveal greater details. For this, resolving power and numerical aperture must be large. A large value of numerical aperture is obtained in an *oil immersion type* microscope. Since λ is small in an *ultra* or *electron* microscope, for high resolution these types of microscopes are used.

The useful magnifying power of a microscope is the ratio of the resolving power of the eye to the resolving power of the microscope.

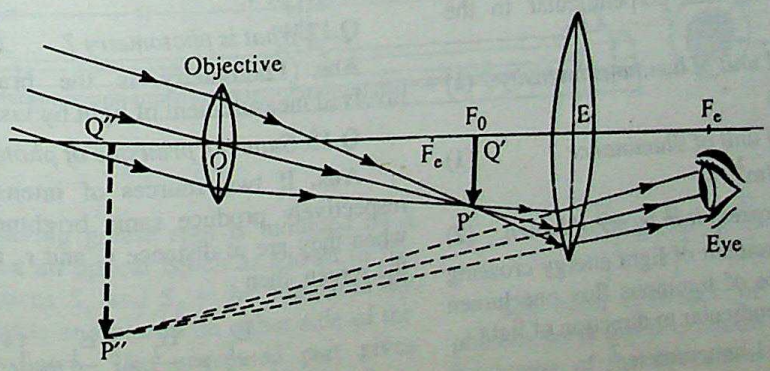
47. The Astronomical Telescope

The astronomical refracting telescope consists of two convex lens. The objective lens O is a lens of large focal length, whereas the eye lens E is one of short focal length. The object lens forms a real, inverted image of the distant object at its focus. This image lies at or within the focus of the eye-lens L, which forms final image at infinity or a finite distance. The magnifying power, M, of refracting telescope is,

$$M = \frac{f_0}{f_e}$$

For large values of M, f_o should be large and f_e small.

Fig below gives the ray diagram showing the formation of image at distance of distinct vision.



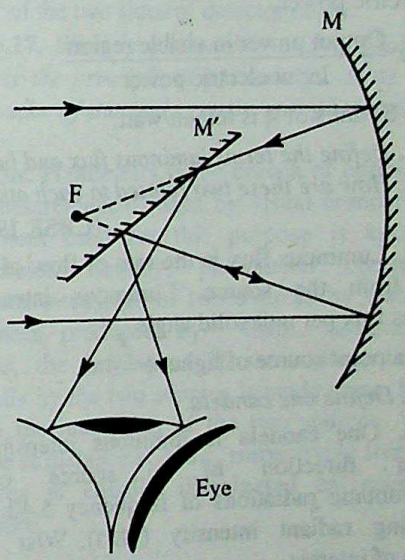
48. The Terrestrial Telescope

In a terrestrial telescope the final image formed is erect instead of inverted as is there in an astronomical telescope. This is achieved by placing an inverted lens between the intermediate image and the eye lens.

49. The Reflecting Telescope

The reflecting telescopes uses a spherical mirror instead of lens to form image of a distant object. The main advantage of a reflecting telescope is that aperture of objective can be quite large. This makes it possible to detect vary faint or vary distant objects. In addition, there is no chromatic aberration. Spherical aberration is minimised using paraboloidal mirrors,

Fig. below gives the ray diagram showing image formation.



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SUBJECTIVE QUESTIONS ON UNIT – IX

Q.1. *Name some common sources of light.* (1)

Ans. Sun, electric bulb, fluorescent tube, sodium vapour lamp, mercury lamp.

Q.2. *Define luminous flux. Define one lumen.* (1)

Ans. Luminous flux is the rate of flow of visible energy from the source. One lumen is the luminous flux emitted per unit solid angle by a uniform point source of luminous intensity one candela.

Q.3. *What is the efficiency of a source of light ? What is its SI units?* (1)

Ans. The efficiency (η) of a source of light is the ratio of the output power in visible region, to that input electric power.

$$\eta = \frac{\text{Output power in visible region}}{\text{Input electric power}}$$

The SI units of η is lumen/watt.

Q.4. *Define the terms luminous flux and luminous intensity. How are these two related to each other?* **(CBSE 1998) (2)**

Ans. Luminous flux is the rate of flow of visible energy from the source. Luminous intensity is lumenous flux per unit solid angle.

For a point source of lights $\phi = 4\pi I$.

Q.5. *Define one candela.* (1)

Ans. One candela is luminous intensity in a particular direction of a source emitting monochromatic radiations of frequency 5.40×10^{14} Hz having radiant intensity (1/683) W/sr in the direction of interest.

Q.6. *Define illuminance.* (1)

Ans. The illuminance (or intensity of illumination) is the amount of light falling per unit area, when the area is held perpendicular to the direction of light.

Q.7. *What is the SI unit of luminous intensity ?* (1)

Ans. Candela

Q.8. *What is the SI unit of illuminance ?* (1)

Ans. Lux = lumen/m^2

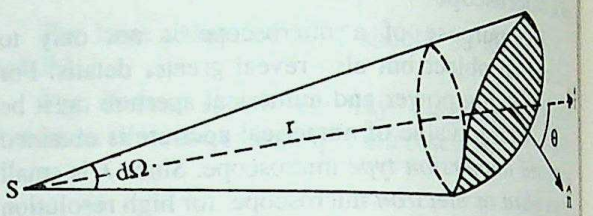
Q.9. *Define lux. Express it in terms of lumen.* (2)

Ans. 1 lux is the amount of light energy crossing unit area from a source of luminous flux one lumen when area is held perpendicular to direction of light.

1 lux = 1 lumen/$meter^2$

Q.10. *State Lambert's Cosine law.* (1)

Ans.



According to Lambert's cosine law the illuminance (E) due to a point source S is proportional to $\frac{dS \cos\theta}{r^2}$, where **dS** is a small area at a distance r from S, and θ is angle between **r** and **dS**. From fig. above.

$d\Omega$ = solid angle subtended by area **dS** at S

$$= \frac{dS \cos\theta}{r^2}$$

The intensity of illumination, $I = \frac{d\phi}{d\Omega}$ and illuminance E is,

$$E = \frac{d\phi}{dS} = I\frac{dS\cos\theta}{dS \cdot r^2} = \frac{I\cos\theta}{r^2}$$

Q.11. *Distance of a point from a point source of light is doubled. By what factor illuminance increases or decreases ?* (1)

Ans. Illuminance is inversely proportional to square of distance. Therefore, illuminance decreases by a factor of 4. (1)

Q.12 *What is photometry ?*

Ans. Photometry is the branch of physics involved measurement of light by visual comparison. (1)

Q.13. *State the principle of photometry.*

Ans. If two sources of intensities E_1 and E_2 respectively produce same brightness on a screen when they are at distance r_1 and r_2 respectively from the screen, then

$$\frac{E_1}{r_1^2} = \frac{E_2}{r_2^2} \text{ or } \frac{E_1}{E_2} = \left(\frac{r_1}{r_2}\right)^2$$

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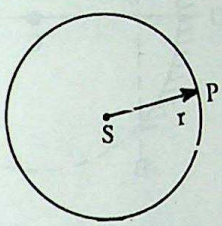
Q.14. *Show that a point source obeys the inverse square law of illuminance.* **(2)**

Ans. Fig below shows a point source S of luminous flux ϕ with S as centre and SP = r, draw a sphere. The surface area of sphere is $4\pi r^2$. The illuminance E, at point P due to S is luminous flux crossing per unit area.



Therefore,

$$E = \frac{\phi}{4\pi r^2}$$

or $$E \propto \frac{1}{r^2}$$

Q.15. *Show that for a point source the total luminous flux $\phi = 4\pi I$, where I is the luminous intensity.* **(2)**

Ans. Let $d\phi$ be luminous flux from a point source in a solid angle $d\Omega$. The luminous intensity, I, by definition is,

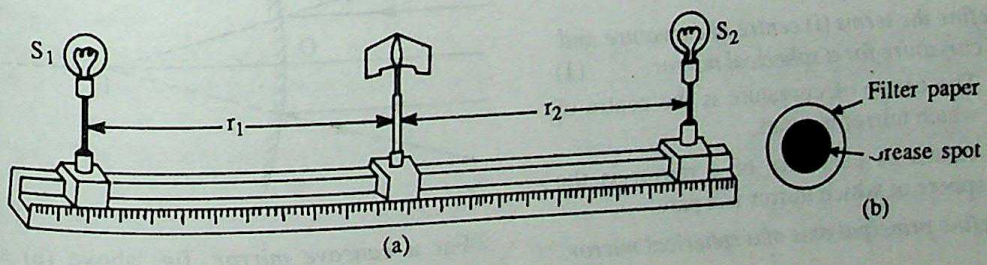
$$I = \frac{d\phi}{d\Omega} \quad \text{or} \quad d\phi = I\, d\Omega$$

On integrating we get, $\phi = I \int d\Omega = 4\pi I$

$$[\because \int d\Omega = 4\pi \text{ radian}]$$

Q.16. *Describe briefly how will you compare the illuminating power of two sources of light using Bunsen's grease spot photometer.*

Ans. *Bunsen's grease-spot photometer :* The photometer essentially consists of a thin, opaque white paper (like a filter paper) having a translucent spot at its centre as shown in fig. (b). The spot is obtained by coating it with wax or oil.



The paper having grease spot is mounted on a vertical upright on an optical bench as shown in fig. (a). The two sources S_1 and S_2 to be compared are mounted on uprights and placed on either side of the grease spot as shown. The ungreased part gives diffused scattering of light falling on the same face, whereas the grease spot gives diffused scattering of light falling on the other face. When the intensity of light on the two sides of the grease spot is not same, the grease spot is clearly visible in the background of the ungreased part. The distance of one of the two sources adjusted so that the grease *spot disappears.* This happens when the intensity on the grease spot from the two sides is same. Let r_1 and r_2 be the distance of the sources S_1 and S_2 from the grease spot and E_1, E_2 de note the intensties of the two sources. Then, we have

$$\frac{E_1}{E_2} = \left(\frac{r_1}{r_2}\right)^2$$

In practice, the grease spot never disappears completely. Usually, one has to adjust *"identical view"* of the two sides of detector paper.

Q.17. *What is photometry and a photometer ? What is the principle of photometry. State the main drawbacks of Bunsen's grease spot photometer.* **(3)**

Ans. Photometry is the branch of optics involved the measurement of light by visual comparison. The instrument used for this purpose is known as a photometer. Usually, photometer compares the luminous intensities of two sources by matching the brightness produced by them. Assuming point sources, the brightness at same area, illuminated normally by the two sources is made same. Let E_1, E_2 denote the intensities of the two sources. When the two are at distance r_1 and r_2 respectively from an area, the area is equally illuminated by each source. Therefore,

$$\frac{E_1}{r_1^2} = \frac{E_2}{r_2^2} \quad \text{or} \quad \frac{E_1}{E_2} = \frac{r_1^2}{r_2^2}$$

The main drawback of Bunsen's grease spot photometer is that it is almost impossible to make the brightness of the two sides of grease spot exactly same.

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Q.18. *Differentiate between luminance and illuminance of a surface.* **(2)**

Ans. Luminance of a surface referes to the brightness of the surface. It is equal to the luminous flux *reflected* per unit area.

Illuminance of a surface is the luminous flux incident per unit area of the surface.

Q.19. *What do you understand by the term optical medium ?* **(1)**

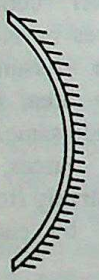
Ans. A medium through which light passes is known as an optical medium.

Q.20. *What do you understand by the terms (i) ray of light and (ii) a beam of light ?* **(1)**

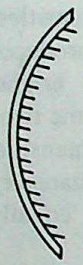
Ans. The path along which light travels in a medium is known as a ray of light. A group of rays of light make a beam of light.

Q.21. *What is a spherical mirror ? Draw a concave and a convex mirror.* **(1)**

Ans. A spherical mirror is a part of spherical surface that has been polished. Fig. below (a) and (b), show a concave and convex mirror respectively.



Concave mirror



convex mirror

Q.22. *Define the terms (i) centre of curvature and (ii) radius of curvature for a spherical mirror.* **(1)**

Ans. (i) The centre of curvature is the centre of the sphere of which mirror is a part.

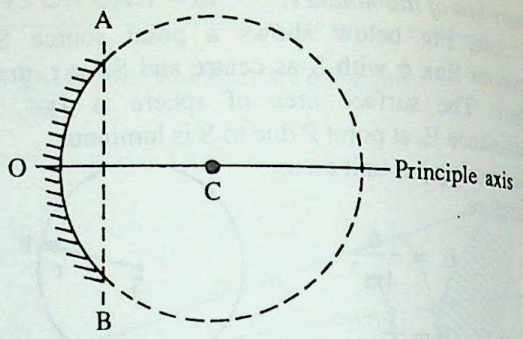
(ii) The radius of curvature of a mirror is the radius of the sphere of which mirror is a part.

Q.23. *Define principal axis of a spherical mirror.* **(1)**

Ans. The principal axis of a spherical mirror is the line joining the pole and the centre of curvature of the mirror.

Q.24. *Define the pole and aperture of a mirror.* **(1)**

Ans. The aperture of a mirror is a measure of the size of mirror. In fig. below, the chord AB equals the aperture of the mirror.



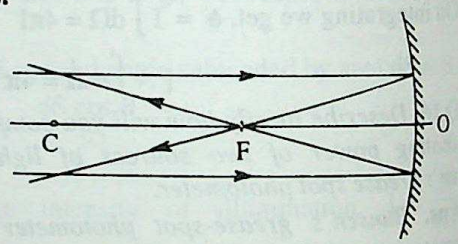
The pole of the mirror (O) is a point that divides mirror into two equal halves.

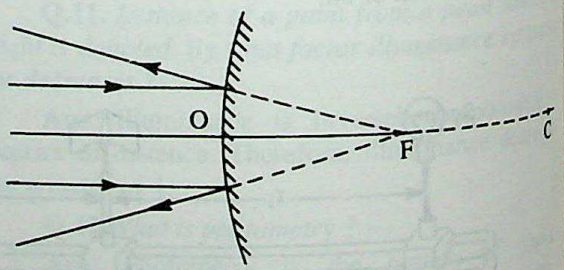
Q.25. *What is the radius of curvature of a plane mirror ?* **(1)**

Ans. Infinity.

Q.26. *Define the focus and focal length of a spherical mirror.* **(2)**

Ans.





For a *concave mirror*, fig. above (a) shows a parallel beam of light incident on it. The reflected rays meet principal axis at a point F. F is the focus of concave mirror.

For a convex mirror, fig. (b) shows a parallel beam of light incident on it. The reflected rays *appear* to meet principal axis at a point F. F is the focus of concave mirror.

The position of focus with respect to the mirror is the focal length of the lens.

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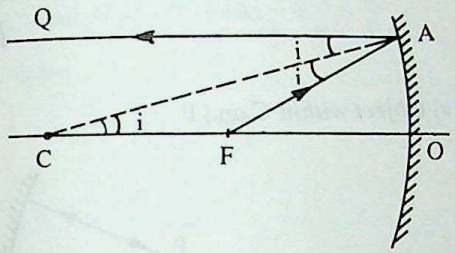
Q.27. *For a spherical mirror show that f = R/2.* **(2)**

Ans. Fig. below shows a concave mirror having centre of curvature at C and focus F. FA is a ray incident on mirror at point A. The reflected ray AQ is parallel to the principal axis. From law of reflection ∠QAC = ∠CAF = i, since AQ is parallel to OC, ∠ACF = i. Now Δ AFC is an isosceles triangle, therefore, CF = AF.



For paraxial rays, AF ≈ OF. Hence, CF = OF or OF = OC / 2. In symbols, f = R / 2.

OR

By definition if an object is placed at the focus, the image is formed at infinity. Therefore, u = f; v=– ∞

From the mirror formula

$$\frac{1}{(-\infty)}+\frac{1}{f}=\frac{2}{R} \text{ or } \frac{1}{f}=\frac{2}{R} \therefore f=\frac{R}{2}$$

Q.28. *Distinguish clearly between a real and a virtual image.* **(2)**

Ans. The rays forming a real image actually meet. The rays forming the real image constitute a convergent beam. A real image can be projected on a screen.

The rays forming a virtual image donot actually meet but appear to meet. The rays forming virtual image make a divergent beam. A virtual image cannot be obtained on a screen.

Q.29. *What are paraxial rays ?* **(1)**

Ans. Rays making small angle with principal axis are known as paraxial rays. If θ is the angle, a ray makes with principal axis, for paraxial ray sin θ ≈ θ

Q.30. *What is the path of the reflected ray, if an incident ray passes through the centre of curvature?* **(1)**

Ans. The reflected ray is along incident ray but travelling in opposite direction.

OR

The ray retraces its path.

Q.31. *A convex mirror of aperture 1 cm has on object placed at a distance of 1 m. Is a sharp image formed by reflection at the mirror ?* **(1)**

Ans. Yes. The incident rays from object are paraxial, therefore, a sharp image is formed.

Q.32. *A concave mirror of aperture 10 cm has a point object placed at a distance of 4 cm. Is the image formed by reflection at the mirror ?* **(1)**

Ans. No. The incident rays are not paraxial, therefore, a sharp reflected image is not obtained.

Q.33. *Discuss, clearly, what is the co-ordinate convention of sign.* **(2)**

Ans. According to co-ordinate convention of signs :

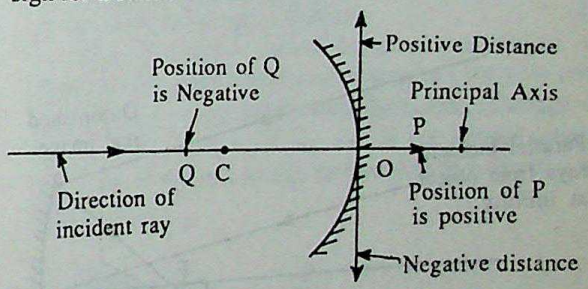
(i) All diagrams are drawn with *incident rays proceeding from left to right.*

(ii) The pole of spherical surface (or optical centre of lens) is chosen as the origin of the co-ordinates.

(iii) All distances measured along principal axis from the pole in *the direction of incident light will be positive.* Distances measured *against the direction of incident rays will be negative.*

(iv) Distance measured perpendicular to the principal axis is *positive* if it is measured upwards from principal axis and vice-versa.

Fig. below shows the co-ordinate convention of sign for a concave mirror



Q.34. *In the co-ordinate convention of sign, what is the meaning of positive or negative sign before u ?* **(1)**

Ans. The – ve sign of u means a real object. The +ve sign of u means a virtual object.

Q.35. *In the co-ordinate convention of sign, what is the meaning of positive or negative sign before v ?* **(1)**

Ans. For *reflection of light:*

The – ve sign of v means a real image, the +ve sign of v means a virtual image.

For *refraction of light:*

The –ve sign of v means a virtual image.

The +ve sign of v means a real image.

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Q.36. *In the co-ordinate convention of sign, is the radius of curvature positive or negative for a (i) convex mirror (ii) concave mirror ?* **(1)**

Ans. (i) Radius of curvature is positive for a convex mirror.

(ii) Radius of curvature is negative for a concave mirror.

Q.37. *Name three most important incident rays together with their corresponding reflected rays, which are used in constructing ray diagrams for spherical mirrors.* **(2)**

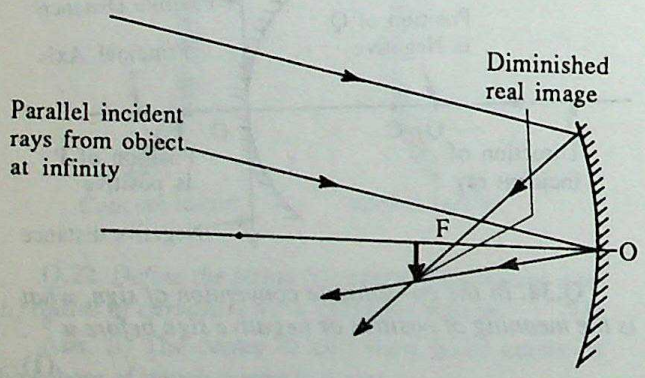
Ans. (i) Incident ray is parallel to the principal axis. The reflected ray passes or appears to pass through focus.

(ii) Incident ray passes or appears to pass through focus. The reflected ray is parallel to the principal axis.

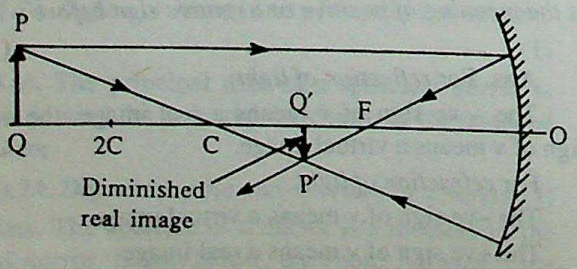
(iii) The incident ray passes or appears to pass through the centre of curvature. The reflected ray coincides with incident ray but is travelling in a direction opposite to that of incident ray.

Q.38. *Draw the ray diagrams showing the formation of images by a concave mirror when an object approaches the mirror from infinity.* **(3)**

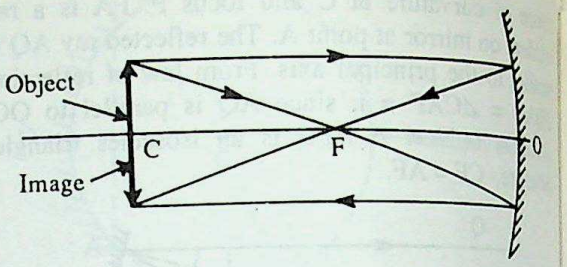
Ans. *(i) Object at infinity*



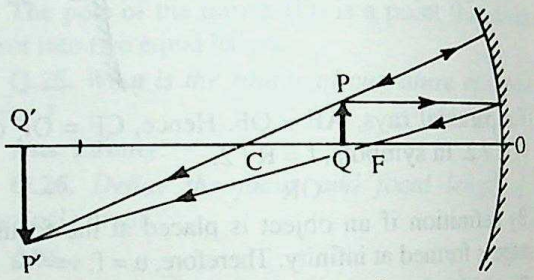
(ii) Object between infinity and 2C



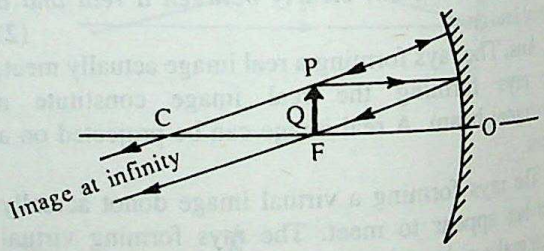
(iii) Object at 2C



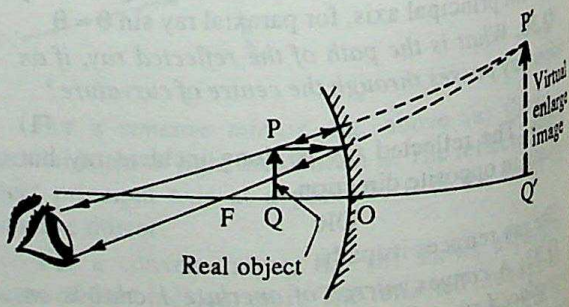
(iv) Object within C and F



(v) Object at F



(vi) Object within pole (O) and focus (F)



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Q.39. *Show that a concave mirror forms a virtual image of the real object placed within its focus. Draw a ray diagram showing the image formation.* **(3)**

Ans. Let a be the distance of the real object from concave mirror. Let focal length of mirror be *e*. Since object is placed within the focus a < e. According to coordinate convention of signs,

$$u = -a,\ f = -e$$

From the mirror formula $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$

we have

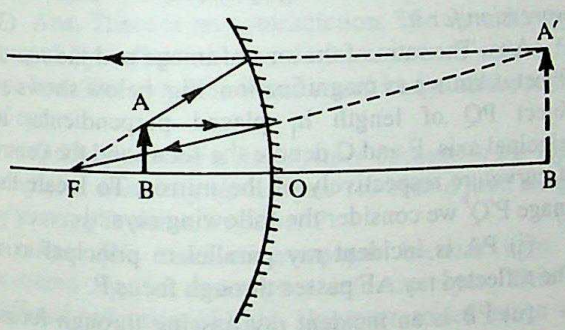
$$\frac{1}{v}+\frac{1}{(-a)}=-\frac{1}{e}$$

or $$\frac{1}{v}=\frac{1}{a}-\frac{1}{e}$$

$$\Rightarrow \quad v=\frac{ae}{(e-a)}$$

Since e > a; v is a positive number. The + ve sign of v means image formed is virtual.

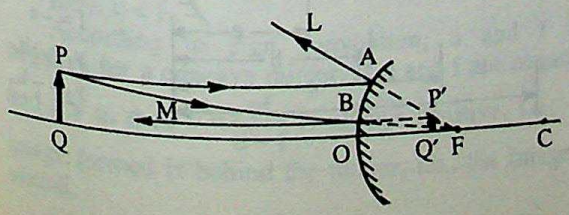
Fig. below shows the ray diagram showing image formation



Q.40. *Draw a ray diagram showing the formation of image by convex mirror of an object. Hence, show that image formed is virtual and diminished.* **(3)**

Ans. PQ is an object of finite size placed on principal axis. F and C denote the focus and the centre of curvature. To find the image, we consider the following rays :

(i) PA is an incident ray parallel to the principal axis. The reflected ray AL appears to pass through the focus F.



(ii) PB is an incident ray that appears to pass through the focus. The reflected ray BM is parallel to principal axis.

The two reflected rays form a divergent beam. The rays appear to meet at P′. Obviously, P′ is image of P formed by the convex mirror. P′Q′ is the image of object PQ. Clearly P′Q′ is virtual, erect and diminished.

Q.41. *Show that a convex mirror always forms a virtual image of a real object.*

Ans. Let R be radius of curvature of a convex mirror. By convention R = + c. Let a real object be placed at a distance a from the mirror. According to co-ordinate convention of signs, u = – a. From the mirror formula $\frac{1}{v}+\frac{1}{u}=\frac{2}{R}$

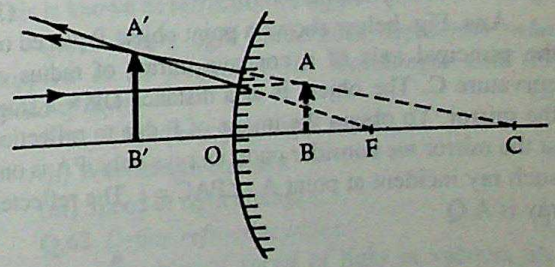
we get $\frac{1}{v}+\frac{1}{(-a)}=\frac{2}{c}$ or $\frac{1}{v}=\frac{2}{c}+\frac{1}{a}$

or $$v=\frac{ac}{2a+c}$$

The above equation shows clearly that v is positive irrespective of value of a. The positive sign of v means a virtual image. Hence, a convex mirror always forms a virtual image of a real object.

Q.42. *Under what circumstances a convex mirror produces a real image ? Explain.* **(2)**

Ans. A convex mirror forms a real image, if *object is virtual* and is placed in between the pole and focus. The ray diagram showing formation of image is shown in fig. below. In fig. AB is the virtual object and A′ B′ is the real image formed due to reflection at convex mirror.



Q.43. *An object is placed between infinity and centre of curvature of a concave mirror. What is the nature of image formed ?* **(1)**

Ans. The image formed is real, inverted diminished. It lies in between C and F.

Q.44. *A concave mirror forms an image of the same size as object. Where is the object placed ?* **(1)**

Ans. Object is at 2C.

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Q.45. *A concave mirror forms an inverted, magnified and real image of an object. What is the location of the object ?* **(1)**

Ans. Object lies in between centre of curvature and focus.

Q.46. *An object is moved towards a spherical mirror from very far off distance. The image formed is found to be always diminished and virtual. What is the nature of the mirror ?* **(1)**

Ans. Convex mirror.

Q.47. *What is the nature of the "rear view" mirror of an automobile?* **(1)**

Ans. Convex mirror.

Q.48. *What is the nature of a shaving mirror ?* **(1)**

Ans. Concave mirror.

Q.49. *What is the nature of the mirror used by a dentist to observe the cavity in the tooth of a patient ?* **(1)**

Ans. Concave mirror.

Q.50. *A large search light uses a reflector. What is the nature of the reflector ?* **(1)**

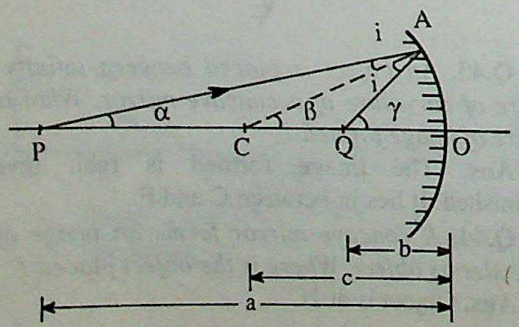
Ans. Paraboloidal mirror.

Q.51. *Define the term magnification. In the co-ordinate convention of signs, what is the interpretation of the positive or negative signs of magnification ?* **(2)**

Ans. The ratio of size of image and object is known as magnification. The positive sign of magnification means erect image. The negative sign of magnification mean inverted image.

Q.52. *Prove the formula* $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$, *connecting the positions of the object and image formed by reflection at a spherical mirror.* **(3)**

Ans. Fig. below shows a point object P placed on the principal axis of a concave mirror of radius of curvature C. The object is at a distance OP = a from the mirror. To obtain the image of P due to reflection at the mirror we consider paraxial rays only. PA is one such ray incident at point A. ∠PAC = i. The reflected ray is A Q.



According to law of reflection, ∠CAP = i. From ΔAPC,

$$\beta = \alpha + i \text{ or } i = \beta - \alpha$$

Similarly, from Δ ACQ; ...(i)

$$\gamma = \beta + i \text{ or } i = \gamma - \beta$$

From eqns (i) and (ii) we get ...(ii)

$$\beta - \alpha = \gamma - \beta \text{ or } \gamma + \alpha = 2\beta \quad ...(iii)$$

For paraxial rays,

$$\alpha = \frac{OA}{OP};\ \beta = \frac{OA}{OC} \text{ and } \gamma = \frac{OA}{OQ} \quad ...(iv)$$

Using eqn (iv), we can rewrite eqn (iii) as

$$\frac{1}{OP}+\frac{1}{OQ}=\frac{2}{OC} \text{ or } \frac{1}{a}+\frac{1}{b}=\frac{2}{c} \quad ...(v)$$

Let u,v and R denote the position of object, image and radius of curvature. According to co-ordinate convention of signs,

$$u = -a,\ v = -b \text{ and } R = -c \quad ...(vi)$$

In terms of positions eqn (v) can be rewritten as

$$\frac{1}{(-v)}+\frac{1}{(-u)}=\frac{2}{(-R)} \text{ or } \frac{1}{v}+\frac{1}{u}=\frac{2}{R} \quad ...(vii)$$

This is the mirror formula.

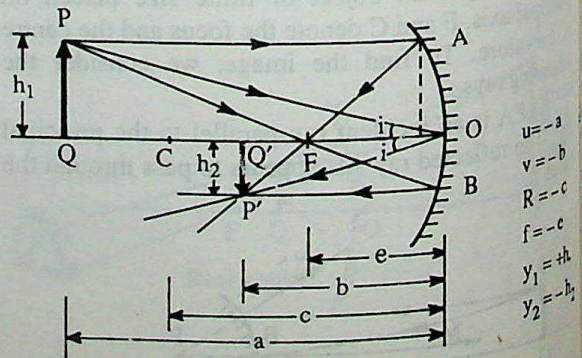
Q.53. *What is magnification ? Obtain an expression for it.* **(3)**

Ans. The ratio of the *size* of image and the *size* of object is known as magnification. Fig. below shows an object PQ of length h_1 placed perpendicular to principal axis. F and C denote the focus and the centre of curvature respectively of the mirror. To locate the image P′Q′ we consider the following rays :

(i) PA is incident ray parallel to principal axis. The reflected ray AF passes through focus F.

(ii) PB is an incident ray passing through focus. The reflected ray BP′ is parallel to principal axis.

(iii) PQ is an incident ray passing through pole O. The reflected ray is OP′ ∠POQ = ∠P′OQ′ = i



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The reflected rays meet at point P', P' is image of P. Draw P' Q' perpendicular to principal axis. P' Q' is the image of object PQ. Let PQ = h_1 be the length of object and P'Q' = h_2, the length of image. According to co-ordinate convention of signs, the size of object $y_1 = + h_1$ and the size of image $y_2 = - h_2$. Hence,

$$m = y_2 / y_1 = -h_2 / h_1 \quad ...(i)$$

From rt angled Δ's POQ and P'OQ'

tan i = i = PQ / OQ and tan i = i = P'Q' / OQ'

$$\therefore \frac{PQ}{OQ} = \frac{P'Q'}{OQ'} \text{ or } \frac{P'Q'}{PQ} = \frac{OQ'}{OQ} \text{ or } \frac{h_2}{h_1} = \frac{b}{a} \quad ...(ii)$$

From eqns (i) and (ii)

$$m = (- b/a) \quad ...(iii)$$

In terms of the object and image position; according to co-ordinate convention, u = –a, v = –b; therefore,

m = – (–v) / (–u) = –v / u

Q.54. *A virtual image cannot be obtained on a screen. However, we see a virtual image. This means the image is obtained on the retina of our eye. Is there a contradiction? Explain.* **(2)**

Ans. There is no contradiction. The virtual image formed by reflection or refraction acts as object for eye lens. The eye-lens forms a real image on the retina of eye.

Q.55. *You read a news paper because of the light it reflects, then why do not you see even a faint image of yourself in the news paper ?* **(2)**

Ans. We read a newspaper because light is scattered by the news print into our eyes. This is *diffused reflection* of light. However, to see image we need regular reflection. This surface of newspaper being rough this is not possible. Therefore, we donot see even a faint reflected image.

Q.56. *Use the mirror formula to show that for an object lying between the pole and focus of a concave mirror, the image formed in always virtual in nature.* **(CBSE 1997) (2)**

Ans. For a concave mirror $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$

$$\Rightarrow v = \frac{uf}{u - f}$$

Here, u < f

According to sign convention, u and f are negative for a concave mirror. If u and f are negative and f > u, then $v = \frac{uf}{u - f}$ is always positive, i.e., image formed is behind the mirror, i.e., the image is virtual.

Q.57. *Establish the relationship between, object distance, image distance and radius of curvature for a concave mirror.* **(CBSE 1996) (3)**

Ans. See answer to question no. 52.

Q.58. *Find the position of an object which when placed in front of a concave mirror of focus length 20 cm, produces a virtual image, which is twice the size of the object.* **(CBSE 1999) (3)**

Ans. Since the image is virtual, therefore,

$$m = +2, \; m = -\frac{v}{u} \Rightarrow -2 = \frac{v}{u} \Rightarrow v = -2u$$

$$f = -20 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$

$$\Rightarrow \frac{1}{-20} = \frac{1}{-2u} + \frac{1}{u} \Rightarrow \frac{-1+2}{2u} = -\frac{1}{20}$$

$$\Rightarrow \frac{1}{2u} = -\frac{1}{20}$$

$$\Rightarrow u = -10$$

Hence, the object is at a distance of 10 cm in front of the mirror.

Q.59. *Draw a ray diagram to show the formation of image of an object placed between the pole and focus of a concave mirror.Obtain the relation between, the object distance (u), image distance (v) and focal length (f) for the given concave mirror. State clearly the assumption involved and the sign convention used.* **(CBSE 1996 Comptt.) (5)**

Ans. See answer to quetion no. 39 and 52.

Q.60. *What is refraction of light ?* **(1)**

Ans. Whenever light goes from one medium to another, it either bends towards or away from normal. This is known as refraction of light.

Q.61. *When light undergoes refraction what happens to (i) frequency (ii) wavelength and (iii) speed of light.* **(2)**

Ans. (i) Frequency remains same.

(ii) Wavelength changes.

(iii) Speed of light changes.

Q.62. *Define refractive index.* **(1)**

Ans. The ratio of speed of light in vacuum and the medium is the refractive index (μ) of the medium. Expressed mathematically, as

$$\mu = \frac{c}{v}$$

c = speed of light in vacuum (or air)

v = speed of light in medium.

Q.63. *What is the significance of refractive index?* **(1)**

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Ans. The refractive index value gives information about direction of bending of refracted ray. In other words, it tells wherther rays will bend towards or away from normal.

Q.64. *Can the absolute refractive index of a medium be less than unit ? Explain.* **(2)**

Ans. No. The absolute refractive index $\mu = c/v$, where c is speed of light in vacuum and v is speed of light in medium. Since v is always less than c; μ can never be less than unit.

Q.65. *Speed of light in vacuum is $3 \times 10^8\ ms^{-1}$. In water (μ = 1.33) speed of light is less than that in vacuum. Explain.* **(2)**

Ans. μ_w = Refractive index of water = $\dfrac{c}{v_w}$

where v_w is speed of light in water.

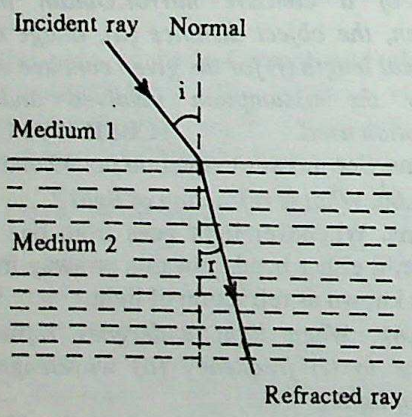
$\therefore\ v_w = \dfrac{3 \times 10^8}{1.33} = 2.25 \times 10^8\ ms^{-1}$

Since $\mu_w > 1$; $V_w < c$.

Q.66. *State Snell's law.* **(1)**

Ans. According to Snell's law :

(1) The incident ray, the refracted ray and the normal at point of incidence lie in same plane.



(2) $\dfrac{\sin i}{\sin r}$ = constant = $_1\mu^2$, where i and r denote the angle of incidence and refraction as shown in fig. above. $_1\mu^2$ is a constant. It is refractive index of medium 2 with respect to medium 1

Q.67. *For a ray of light undergoing refraction from a combination of three media of refractive indices μ_1, μ_2 and μ_3 respectively, show that*

$$_1\mu^2 \times\ _2\mu^3 \times\ _3\mu^1 = 1$$

Ans. Let v_1, v_2, v_3 denote speed of light in media of absolute refractive indices μ_1, μ_2 and μ_3 respectively. By definition:

$$\mu_1 = \frac{c}{v_1};\ \mu_2 = \frac{c}{v_2} \text{ and } \mu_3 = \frac{c}{v_3}$$

Let $_1\mu^2$ be the refractive index of medium 2 with respect to medium 1. Then,

$$_1\mu^2 = \frac{\mu_2}{\mu_1} = \frac{c/v_2}{c/v_1} = \frac{v_1}{v_2}$$

Similarly,

$$_2\mu^3 = \frac{\mu_3}{\mu_2} = \frac{v_2}{v_3}$$

and $$_3\mu^1 = \frac{\mu_1}{\mu_3} = \frac{v_3}{v_1}$$

Now,

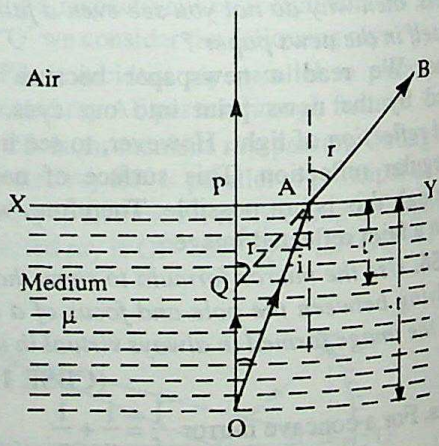
$$_1\mu^2 \times\ _2\mu^3 \times\ _1\mu^3 = \frac{v_1}{v_2} \times \frac{v_2}{v_3} \times \frac{v_3}{v_1} = 1.$$

Q.68. *Show that refractive index of a medium*

$$\mu = \frac{\text{Real depth}}{\text{Apparent depth}}.$$

Ans. Fig. below shows a boundary XY separating air and a medium, say water, of refractive index μ. O is a point on the bottom of water. OP = t real depth. OA is a ray incident from O at point A on XY and AB is the refracted ray. According to Snell's law,

$$\mu \sin i = 1 \sin r \quad \ldots(i)$$



In fig. PQ = t' is the apparent depth. Considering point A to be very near P angle of incidence i and angle of refraction r can be considered small

Hence, $\tan i = \sin i$, and $\tan r = \sin r$ ...(ii)

From rt, angled Δ APO. ...(iii)

$\tan i = PA/OP$

and from rt angled Δ APQ

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$$\tan r = PA/PQ \quad \text{...(iv)}$$

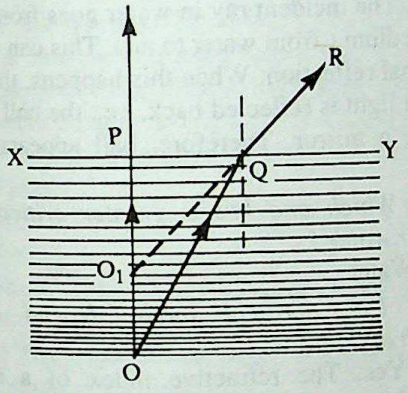
Combining eqns (i), (ii), (iii) and (iv) we get

$$\mu = \frac{\sin r}{\sin i} = \frac{\tan r}{\tan i} = \frac{PA/PQ}{PA/PO}$$

$$\mu = \frac{PO}{PQ} = \frac{\text{Real depth}}{\text{Apparent depth}}.$$

Q.69. *Explain why does a pond of water appear shallower than what it is.* **(2)**

Ans. In fig. below XY is the surface of water in pond and O is a point at the bottom of pond. OP is the actual depth of pond. OQ is a ray incident at Q from O. QR is the refracted ray. Since light is going from denser to rarer medium, it bends away from the normal. The refracted ray QR appears to come from point O_1. The apparent depth of pond is O_1P. Obviously, O_1 P is less than OP. Therefore, a pond of water appears to be shallower than what it is.

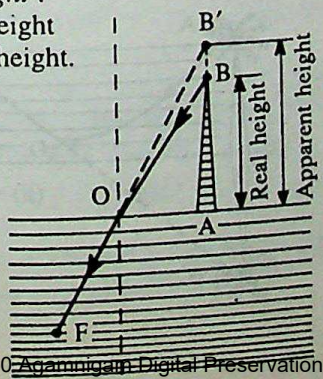


Q.70. *An ink mark on a sheet of paper is viewed through a glass slab of thickness t and refractive index μ appears to be raised. What is the distance by which the mark appears to be raised ?* **(1)**

Ans. $t\left(1 - \frac{1}{\mu}\right)$

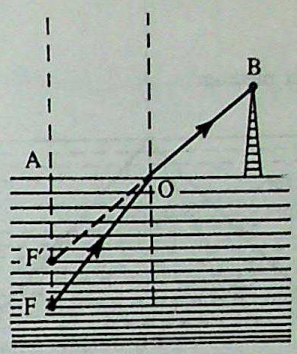
Q.71. *A fish in a pond of water sees a bird sitting on top of a tree. Is the apparent height of bird more or less than the real height ?* **(1)**

Ans. Apparent height is more than the real height. This is shown in fig.



Q.72. *A bird sees a fish inside a pond of water. Is the real depth of fish more or less than the apparent depth ?* **(1)**

Ans. The apparent depth of fish according to bird is less than the real depth. This is shown in fig.



Q.73. *Does the apparent depth of a tank of water change, if viewed obliquely ?* **(1)**

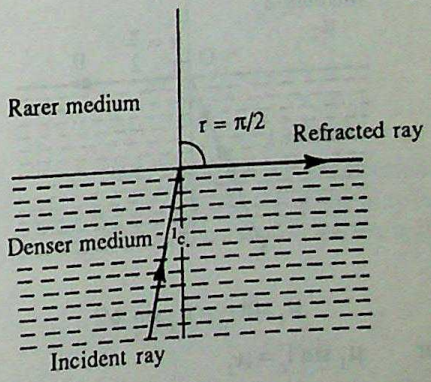
Ans. Yes.

Q.74. *Does the apparent depth of a tank of water increase or decrease when viewed obliquely ?* **(1)**

Ans. Decreases.

Q.75. *What is critical angle of incidence ?* **(1)**

Ans. Critical angle is the angle of incidence (i_c) in denser medium so that angle of refraction in rarer medium is π/2. This is shown in fig. below.



Q.76. *What happens if the angle of incidence is more than critical angle ?* **(1)**

Ans. When angle of incidence (i) is more than critical angle (i_c), no light is refracted into the rarer medium. The light is reflected back, completely into the denser medium.

Q.77. *What is total internal reflection ?* **(2)**

Ans. Let light go from a denser to a rarer medium. If angle of incidence (i) is greater than the critical angle of incidence (i_c), no light is refracted

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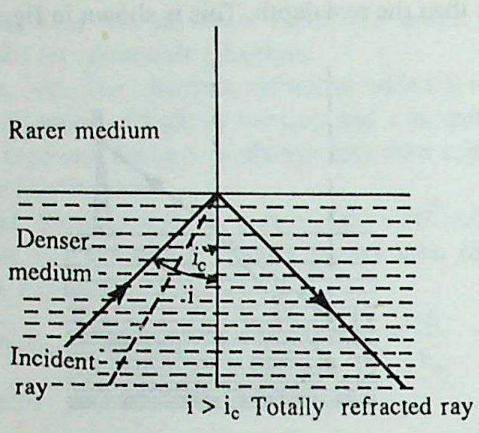
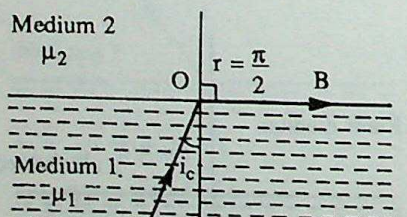
into second medium. The whole of light is reflected back into first medium. This is known as total internal reflection. Fig. below shows a ray of light undergoing total internal reflection.



Q.78. *Light goes from a medium 1 of refractive index μ_1 to another medium 2 of refractive index μ_2. $\mu_2 < \mu_1$. Obtain an expression for the critical angle of incidence.* **(2)**

Ans. Fig. below shows incident ray AO in medium 1, so that the angle of refraction $r = \pi/2$. The angle of incidence $i = i_c$, the critical angle of incidence. From Snell's law,



$$\mu_1 \sin i_c = \mu_2 \sin \pi/2$$

or $\mu_1 \sin i_c = \mu_2$

or $i_c = \sin^{-1}(\mu_2/\mu_1)$.

Q.79. *Why diamond shines much brighter than ordinary glass ?* **(2)**

OR

Why do diamonds sparkle ? **(2)**

Ans. The refractive index (μ) of diamond is high. The critical angle of incidence is about 24°. Since i_c is small, a ray of light entering into diamond undergoes repeated total internal reflections at various faces before it emerges out. Due to large number of total internal reflections diamonds sparkle. However, for ordinary glass ($\mu = 1.5$) the critical angle of incidence is about 42°. This is much more than 24°, Hence, a ray of light does not undergo repeated total internal reflection inside glass. Therefore, glass does not sparkle.

Q.80. *The refractive index of diamond is much greater than that of the ordinary glass. Is this fact of some use to a diamond cutter ? Explain.* **(2)**

Ans. Yes. Refer to question no. 79.

Q.81. *A ball coated with 'lamp black' is lowered into a glass tank containing water, when viewed from outside the tank, what is the colour of the ball ? Explain.* **(2)**

Ans. The ball appears *silvery* bright. This is due to total internal reflection as explained in what follows.

A very thin air film is trapped in between the ball and water. The incident ray in water goes from denser to rarer medium (from water to air). This can undergo total internal reflection. When this happens, the whole of incident light is reflected back, i.e., the ball appears to act like a mirror. Therefore, ball appears silvery bright.

Q.82. *Which one has a greater critical angle diamond or water ?* **(1)**

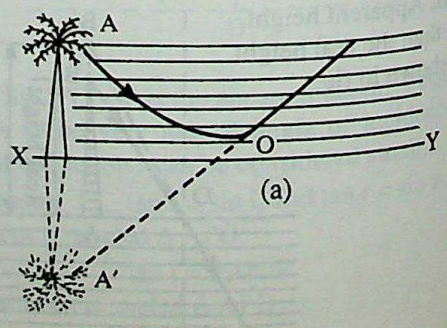
Ans. Water

Q.83. *Does critical angle depend on the wavelength of light ?* **(1)**

Ans. Yes. The refractive index of a medium depends on wavelength of incident light. Critical angle in turn depends on refractive index. Therefore, critical angle depends on wavelength of light.

Q.84. *On a hot summer day in a desert, one sees the reflected image of a distant part of sky. This is an optical illusion known as mirage. Explain.* **(2)**

Ans. Mirage is an *optical illusion* due to total internal reflection. It is observed either over hot deserts or in very cold countries near sea side.



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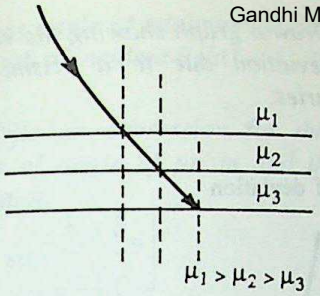


Fig. (a) above shows mirage observed over hot deserts. During day time due to sun the surface of earth becomes very hot. The layer of air in contact with earth is hotter and, therefore, optically less dense. The refractive index of various layers of air decreases on moving up from the surface of earth. A ray of light starting from a point A on a high tree travels from a denser to rearer medium and bends away from normal. This is shown on an enlarged scale in fig. (b). At a point O, the angle of incidence exceeds critical angle and total internal reflection takes place. The reflected ray appears to come from A′. A distant observer, sees an inverted image of tree as if the tree was standing besides a pond of water. Actually there is no water around tree.

Q.85. *Write two conditions for total internal reflection.* **(1)**

Ans. (i) Light must go from a denser to a rarer medium.

(ii) The angle of incidence must be more than the critical angle of incidence.

Q.86. *What are optical fibres? On what principle does it work ? Give three applications of these fibres.* **(CBSE 1999) (3)**

Ans. An optical fibre is a pipe of a transparent medium of refractive index μ_2. It is covered with a coating of a material of refractive index μ_2. $\mu_1 > \mu_2$. Optical fibre works on the principal of total internal reflection.

Optical fibres are used in:

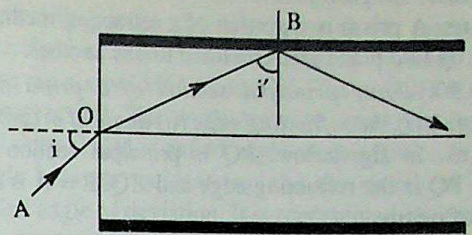
(i) Medical examination of human body i.e. in endoscopy.

(ii) Transmission and reception of electrical signalls by converting them first into light signals.

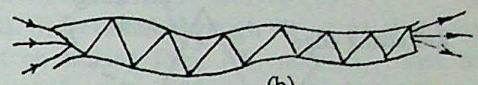
(iii) Telephone and other transmitting cables.

Q.87. *Explain with a ray diagram, how optical fibred transmit signals.*

Ans. Fig (a) shows a signal entering light pipe at O and undergoing total internal reflection at B.



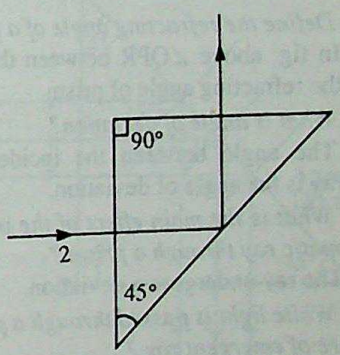
(a)



(b)

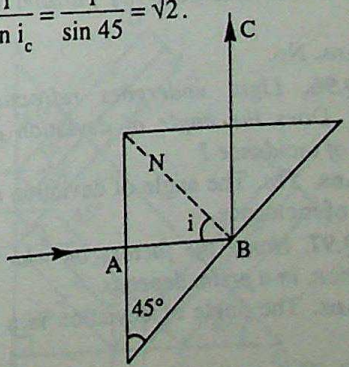
Fig. (b) shows a long light pipe. The signal entering at one end undergoes repeated total internal reflection and emerges out at the other end.

Q.88. *Figure below shows a triangular prism of glass. A ray incident normal to one face is totally reflected. What can you conclude about the minimum value of index of refraction of glass ?* **(2)**



Ans. Since the incident ray undergoes total internal reflection at point B; the angle of incidence $i = 45°$ must be equal to the critical angle of incidence (i_c)

$$\therefore \quad \mu = \frac{1}{\sin i_c} = \frac{1}{\sin 45} = \sqrt{2}.$$



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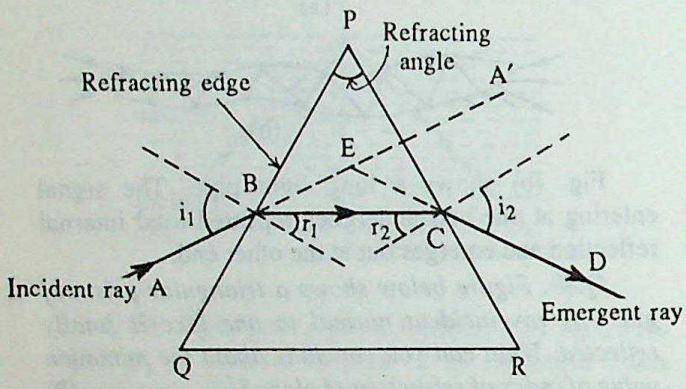
Q.89. *What is a prism ?* (1)

Ans. A prism is a portion of a refracting medium bound by two plane faces inclined to one another.

Q.90. *Draw principal section of a prism and mark on it (i) the refracting edge (ii) angle of prism.*(1)

Ans. In fig. below. PQ is principal section of prism. PQ is the refracting edge and ∠QPR = A is the angle of prism.



Q.91. *Define the refracting angle of a prism.* (1)

Ans. In fig. above ∠QPR between the faces PQ and PR is the refracting angle of prism.

Q.92. *What is angle of deviation?* (1)

Ans. The angle between the incident and the emergent ray is the angle of deviation.

Q.93. *What is the main effect of the passage of a monochromatic ray through a prism ?* (1)

Ans. The ray undergoes a deviation.

Q.94. *White light is passed through a prism. What is the nature of emergent ray ?* (1)

Ans. The emergent rays consist of various coloured rays. For white incident ray the emergent rays are VIBGYOR.

Q.95. *A monochromatic ray passes through a prism. Is the emergent ray parallel to the incident ray?* (1)

Ans. No.

Q.96. *Light undergoes refraction through a prism. Does the angle of deviation depend on the angle of incidence ?* (1)

Ans. Yes. The angle of deviation depends on the angle of incidence.

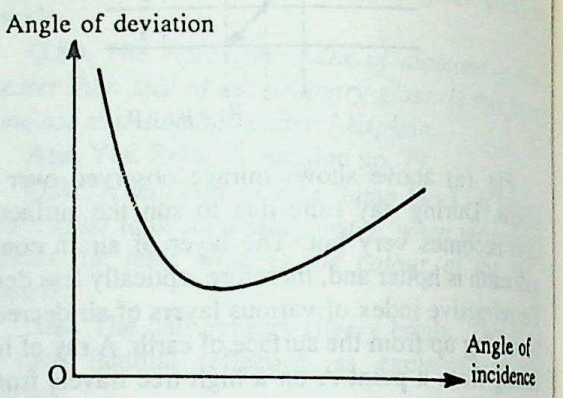
Q.97. *Name the factors on which the angle of deviation, in a prism depends.* (1)

Ans. The angle of deviation in a prism depends on :

(i) The angle of incidence, (ii) The angle of emergence, and (iii) the angle of prism.

Q.98. *Draw a graph showing the variation of the angle of deviation due to a prism, as angle of incidence varies.* (1)

Ans.



Q.99. *What is angle of minimum deviation?*

Ans. The least value of angle of deviation is known as angle of minimum deviation.

Q.100. *A ray undergoes minimum deviation in a prism. What is the inclination of ray inside prism, with the base of the prism ?* (1)

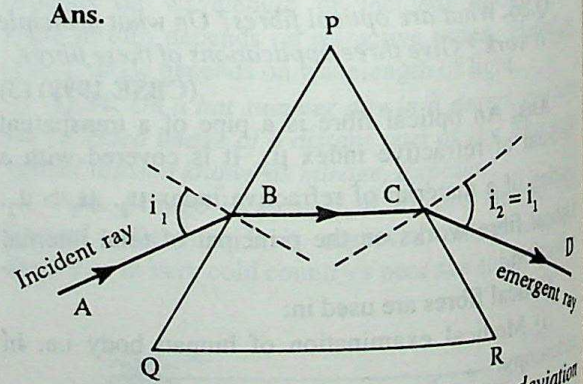
Ans. Inside the prism, the minimum deviated ray is *parallel* to the base of prism.

OR

Angle between minimum deviated ray and base of prism is zero degree.

Q.101. *Trace the path of a ray through a prism kept in the minimum deviation position.* (1)

Ans.



Q.102. *How is the angle of minimum deviation related to the angle of incidence and the angle of emergence?* (1)

Ans. Let i_1 be angle of incidence for a ray undergoing minimum deviation. A is angle of prism. The angle of emergence (i_2) equals angle of incidence (i_1). The angle of minimum deviation (δ_m) is

$$\delta_m = 2\, i_1 - A.$$

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Q.103. *Does angle of minimum deviation depend on the wavelength of incident light?*

Ans. Yes.

Q.104. *Write an expression for the refractive index in terms of angle of prism and the angle of minimum deviation.* **(1)**

Ans. $$\mu = \frac{\sin\left[\frac{A+\delta_m}{2}\right]}{\sin\left(\frac{A}{2}\right)}$$

where A = angle of prism, δ_m = angle of minimum deviation, μ = refractive index of prism.

Q.105. *A prism is able to produce the spectrum of white light, whereas a glass slab of the same material as prism does not produce any spectrum. Explain.* **(2)**

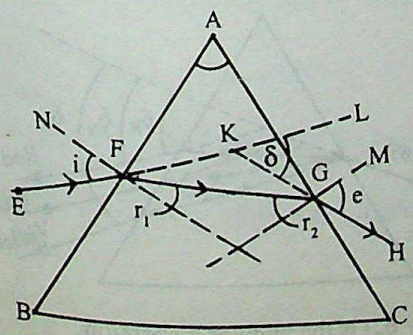
Ans. In a glass slab the emergent rays are parallel to incident ray. The incident white light does break up into constituent colour, as it undergoes refraction in glass slab. The eye-lens, however, focuses all these different coloured rays to same point on retina. The final image formed, therefore, appears white.

In a prism of same material as glass slab dispersion occurs as in glass slab. But the emergent different coloured rays do not form a parallel beam. The eye-lens, therefore, forms images of the different colours at different points on the retina.

Q.106. *Discuss the phenomenon of refraction through a prism.*

Ans. ABC shows a principal section of an equilateral prism, such that ∠A is the angle of prism.

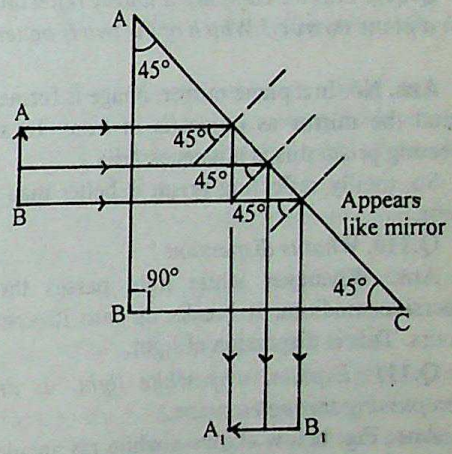
EF is an incident ray, meeting the refracting surface AB at point F, such that ∠EFN is the angle of incidence. As the incident ray is travelling from optically less dense medium to optically more dense medium, therefore, it bends towards normal NF and, hence, travels through glass along FG, such that 'r_1' is the angle of refraction, on refracting face AB.

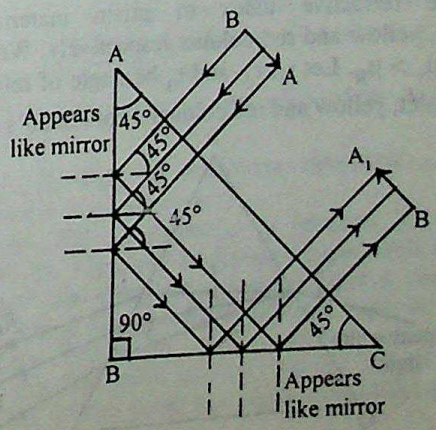


The refracted ray FG, on emerging out from glass is travelling from optically more dense medium to optically less dense medium. Thus, it deviates a way from the normal MG, along GH. The ray GH is called emergent ray. The angle between emergent ray GH and normal GM is called angle of emergence (e). The angle between incident ray and the emergent ray is called angle of deviation. It is represented by letter δ.

Q.107. *How would you use a right angled prism to turn a ray through (i) 90° and (ii) 180°.* **(2)**

Ans. (i) **Deviation through 90°.** A parallel beam of light on striking force AB, normally, does not suffer any refraction, and hence, strike face AC at an angle of 45°. Since critical angle for glass is 42°, therefore, total internal reflection takes place. The beam, thus, bames angle of reflection of 45°, and hence, on the whole turn through 90°. It strike face BC normally and emerges out in air. Thus, fig. face AC of prism acts like mirror.





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(ii) **Deviation through 180°.** Consider a parallel beam of light, incident normally on the face AC of right angled isosceles prism. The beam passes on undeviated till a strikes face AB at angle of 45°. Since critical angle for glass is only 42°, therefore, total internal reflection takes place and the beam turns through a total angle of 90, so as to strike the race BC, at an angle of 45°. Thus, another total internal reflection takes place and beam further turns through an angle of 90°, so as to strike face AC normally. From this face the beam emerges out with suffering any refraction.

Thus, on the whole, beam turns through 180° and the surface AB and BC act as totally reflecting mirrors.

Q.108. *For small angled prism, what is the relation between angle of incidence and angle of deviation?* **(1)**

Ans. For small angled prisms the angle of deviation does not depend on angle of incidence.

Q.109. *Can we compare a totally reflecting prism with a plane mirror ? Which of the two is better ?* (2)

Ans. No. In a plane mirror, image is formed as far behind the mirror as object is in front. In a totally reflecting prism this is not necessarily.

So, totally reflecting prism is better than a plane mirror.

Q.110. *What is dispersion ?* **(1)**

Ans. Whenever white light passes through a dispersive medium, it breaks up into its constituent colours. This is dispersion of light.

Q.111. *Explain, why white light is dispersed when passing through a prism.* **(2)**

Ans. Fig. below shows a white ray incident on a prism. The angle of incidence for all constituent colours of white light is same. Let μ_v, μ_y and μ_r denote refractive index of prism material for violet, yellow and red colours respectively. We know $\mu_v > \mu_y > \mu_R$. Let r_1, r_2 and r_3 be angle of refraction for violet, yellow and red colours. From Snell's law,

$$\mu_v = \frac{\sin i}{\sin r_1} ; \mu_y = \frac{\sin i}{\sin r_2} ; \mu_R = \frac{\sin i}{\sin r_3}$$

since $\mu_v > \mu_y > \mu_R$; $\sin r_1 < \sin r_2 < \sin r_3$

or $r_1 < r_2 < r_3$

This is shown in fig. above The different colours move in different directions inside the prism. Refraction of each colour takes place at the second face of the prism. The emergent ray has different direction depending on the colour.

In other words, incident white light breaks up into its constituent colours on undergoing dispersion.

Q.112. *What is dispersion? Explain the phenomenon of dispersion and define dispersive power.* (3)

Ans. The breaking up of white light into its constituent colours in passing through a refracting medium is known as dispersion.

For explianation of dispersion please refer to question no. 111.

The dispersive power ω of a medium is angular dispersion per unit deviation. Let μ_v μ and μ_R be refractive index of a medium for violet, yellow and red colours respectively. If δ_v, δ and δ_R is angle of deviation of violet, yellow and red colours for a small angled (α) prism. Then $\delta_v = (\mu_v - 1)\,\alpha$; $\delta = (\mu - 1)\alpha$ and $\delta_R = (\mu_R - 1)\,\alpha$

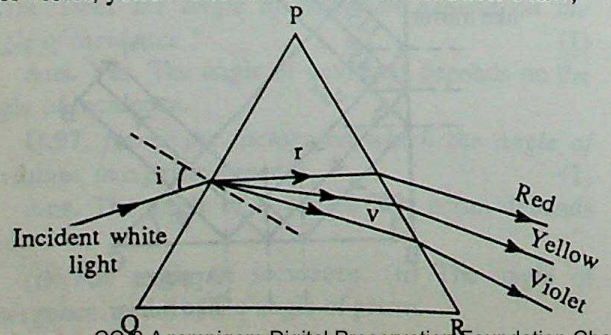
$$\omega = \frac{\delta_v - \delta_r}{\delta} = \frac{(\mu_v - 1)\,\alpha - (\mu_R - 1)\,\alpha}{(\mu - 1)\,\alpha}$$

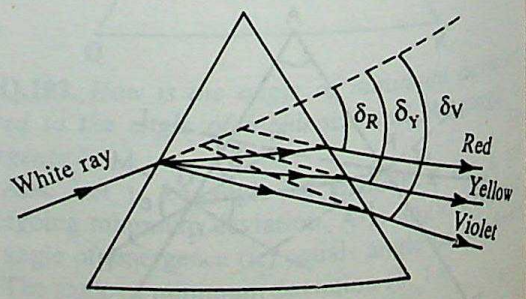
$$= \frac{\mu_v - \mu_R}{\mu - 1} = \frac{d\mu}{\mu - 1},$$

where $d\mu = \mu_v - \mu_R$ is the change in refractive index.

Q.113. *Define (i) angular dispersion (ii) mean deviation and (iii) dispersive power.* (3)

Ans. Fig. below shows dispersion of a white incident ray by a prism. Let δ_v, δ and δ_R be the deviation of violet, yellow and red colours respectively.





(i) $\delta_v - \delta_R$) is the angular dispersion.

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(ii) the deviation of yellow colour is the mean deviation.

(iii) the dispersive power ω of a medium is angular dispersion per unit deviation. It is constant for a medium, for small angled prism.

Q.114. *Is the dispersive power of a medium constant ?* (1)

Ans. In general dispersive power of a medium is not a constant. However, it is a constant for small angled prisms.

Q.115. *Does the dispersive power of a prism depend on the angle of the prism ?* (1)

Ans. Yes.

Q.116. *Express dispersive power in terms of refractive index.* (1)

Ans. Dispersive power = $\omega = \dfrac{\mu_v - \mu_R}{\mu - 1}$

μ_v = refractive index of material for violet colour.

μ_R = refractive index of material for red colour.

$\mu = \dfrac{\mu_v + \mu_R}{2}$ = refractive index for yellow colour.

Q.117. *How is the refractive index of a medium related to the wavelength of incident light ?* (1)

Ans. $\mu = A + \dfrac{B}{\lambda^2}$

A and B are two constants known as Cauchy's constant. This equations is known as Cauchy's relation

Q.118. *The wavelength of red light is almost double than that of violet light. Is refractive index of a medium also more for red colour as compared to refractive index for violet colour ?* (1)

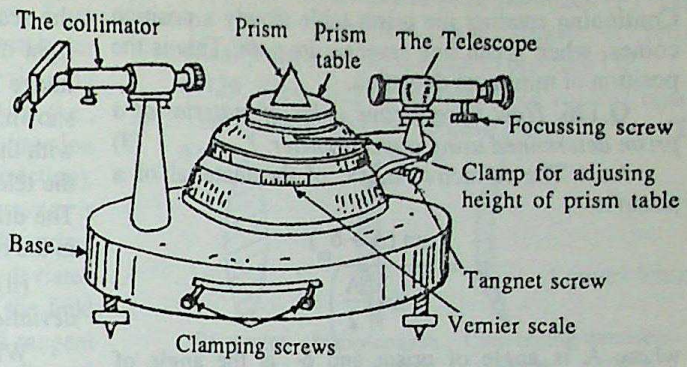
Ans. No. Since refractive index is inversely proportional to wavelength; refractive index for red colour (μ_R) is *less* than refractive index for violet colour (μ_v)

Q.119. *Name the different parts of a spectrometer.* (1)

Ans. (i) The collimator (ii) the prism table and (iii) the telescope.

Q.120. *Draw a labelled diagram of a spectrometer.* (2)

Ans. Fig. below shows the labelled diagram of a spectrometer



Q.121. *Why is spectrum usually observed in the minimum deviation position ?* (2)

Ans. In the minimum deviation position the spectrum observed is most intense.

Q.122. *What is the function of a collimator in a spectrometer ?* (1)

Ans. To produce a parallel beam of light. This beam is incident on the prism.

Q.123. *What is the function of a prism table in a spectrometer ?* (1)

Ans. The prism table used to place prism on spectrometer. By rotating the prism table about a vertical axis through its centre, the angle of incidence on prism can be varied.

Q.124. *Explain, how a spectrometer is adjusted in "normal adjustment"* (2)

Ans. In the "normal adjustment" of a spectrometer the collimator produces a parallel beam of light and the telescope receives this beam.

The telescope is pointed towards a distant object say a tree and the focusing screw adjusted till a sharp image is seen. The telescope is adjusted to focus a parallel beam.

The collimator slit is illuminated with a source and viewed through the telescope. The focussing screw of collimator is adjusted till a sharp image of slit is seen in the telescope.

The spectrometer is now adjusted in its normal adjustment

Q.125. *How is minimum deviation position obtained in a spectrometer ?* (2)

Ans. The spectrometer is adjusted in normal adjustment. The prism is placed on prism table in such a manner that spectrum of incident light is observed. Green line in the spectrum is adjusted to be viewed in telescope. The prism table is rotated say towards collimator. The green line also rotates. The telescope is moved, so that green line remains in field of view.

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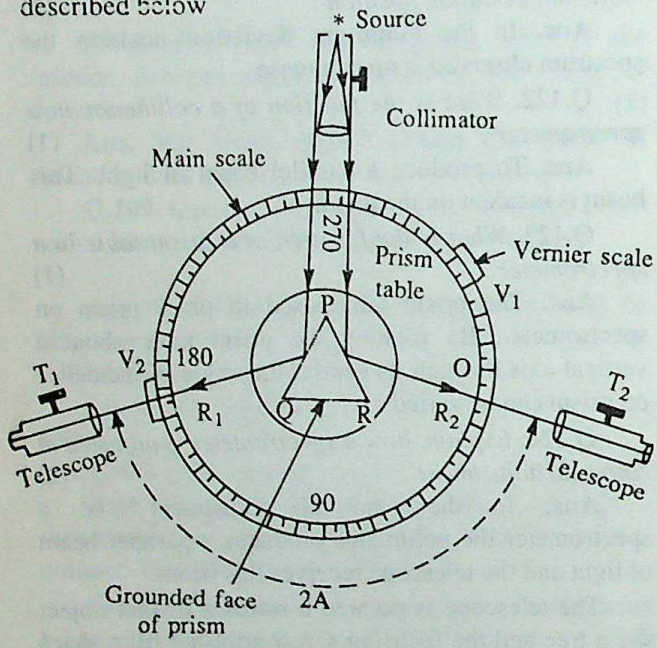
The direction in which green line moves is noted. Continuing rotating the prism table slowly a position comes, when green line *reverses its path*. This is the position of minimum deviation.

Q.126. *How is refractive index of material of a prism determined using a spectrometer ?* **(3)**

Ans. The refractive index, of the material of a prism is

$$\mu = \frac{\sin (A + \delta_m)}{\sin \left(\frac{A}{2}\right)}.$$

where A is angle of prism and δ_m is the angle of minimum deviation. A and δ_m are determined as described below



(i) *Determination of Angle of Prism*

Mount the prism on the prism table as shown in fig. The ground face of the prism is towards the telescope and the centre of the prism coincides with the centre of the prism table.

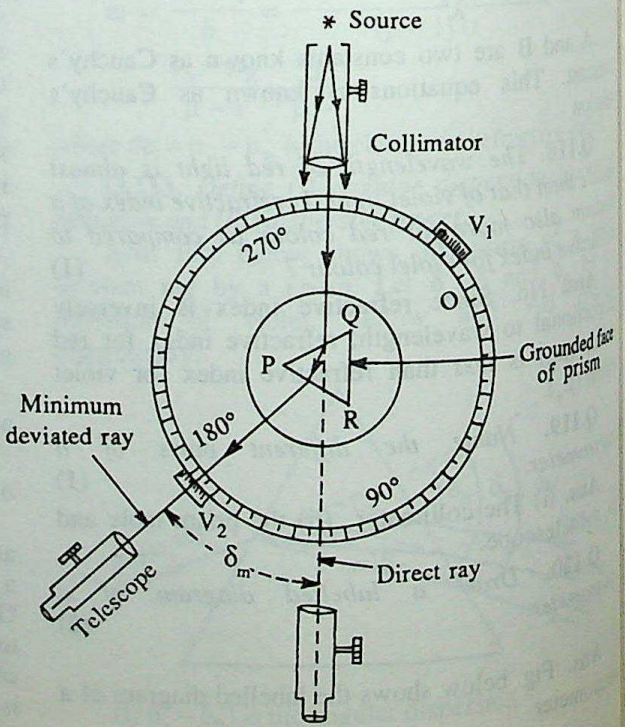
Parallel rays from the collimator fall on the face PQ and PR of the prism as shown in fig. The reflected rays from the two faces are R_1 and R_2 respectively. On keeping prism table locked, move the telescope so as to receive the reflected ray R_1. Telescope is in position T_1 shown in fig.

By using the tangent screw of the telescope make the reflected image R_1 coincide with the vertical cross-wire in the field of view of the telescope. Record the readings of the scales V_1 and V_2. Now turn the telescope to the right of the incident ray so as to receive the reflected image R_2 of the slit. The telescope is in position T_2 as shown. Again make the reflected image R_2 coincide with the vertical cross-wire using the tangent screw of the telescope. Record the readings of scale V_1 & V_2. The difference in the readings of the scale V_1 and V_2 in the two positions gives 2A.

(ii) *Determination of the angle of minimum deviation (δ_m).*

Without placing prism on the prism table bring the telescope in front of the collimator. Coincide the *direct image* of the slit with the vertical cross-wire in the field of view of the telescope. Record the reading of scale V_1 and V_2. This is the *direct-ray reading.*

Place the prism on the prism table with ground face towards one side (i.e., right or left) of incident rays as shown in fig. The rays incident on the face PQ of the prism emerges out of the face PR. In this process the ray undergoes deviation and dispersion. In case source of light is monochromatic (like sodium lamp) the emergent ray is single of same colour as that of incident ray. However, if incident ray is white (or polychromatic), as is the case when mercury lamp is used as source; the emergent rays are coloured. Turn the telescope, so as to receive the emergent ray as shown in fig. Gradually, rotate the prism table, say in clock wise



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direction. The emergent ray of a particular colour (say, yellow) will also turn say in clockwise direction. Keep on rotating the telescope so as to keep, this particular ray always in the field of view. A stage will soon come, when the table is rotated in same direction (i.e., clockwise), but the emergent ray reverses its direction (i.e., emergent ray now rotates in clockwise direction). The position where the emergent ray *just reverses* is the position of minimum deviation. Lock the prism table in this position and make the minimum deviated rays coincide with the vertical cross-wire in the field of view of the telescope. Use clamping and tangent screw attached to the telescope to achieve this. Record the readings of scales V_1 and V_2. The difference in readings of V_1 and V_2 in the minimum deviated and direct ray position gives angle of minimum deviation δ_m.

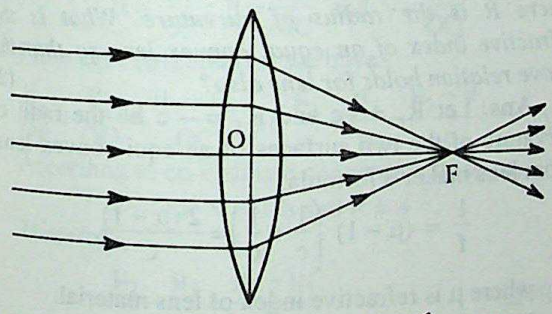
Q.127. *For a lens define : Principal axis.* (1)

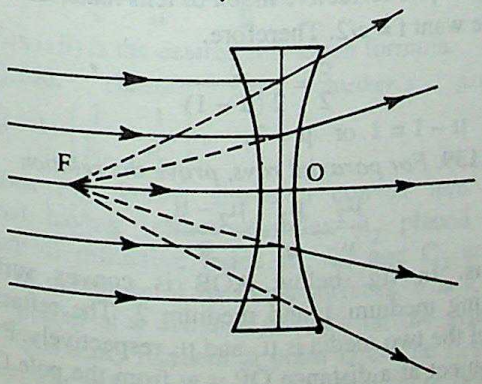
Ans. (i) Principal axis of a lens is the line going center of curvature of the two lens surfaces.

Q.128. *Define principal focus and focal length for a lens.* (1)

Ans. Consider a beam of light parallel to principal axis on the lens.

(a) *Convex Lens :* The refracted rays meet at a point F on the principal axis as shown in fig. (a).



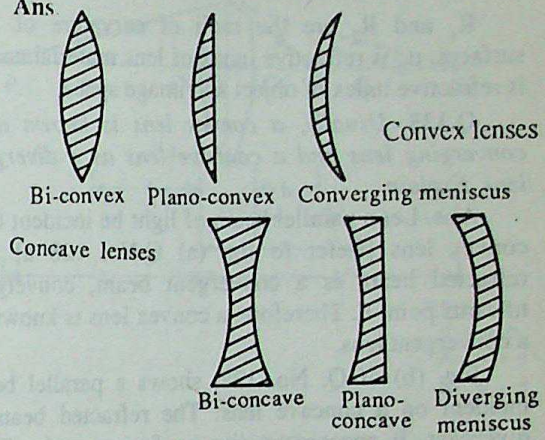


(b) *Concave Lens:* The refracted rays appear to meet at a point F on principal axis as s hown in fig. (b).

The point F is known as principal focus (F). The position of F gives the focal length of lens. Numerically, focal length is equal to distance OF.

Q.129. *Show diagrammatically the various types of (i) convex lenses and (ii) concave lenses.* (2)

Ans.



Q.130. *What is the deviation produced by a thin lens of a ray passing through the optical centre?* (3)

Ans. Zero . In other words, a ray passing through optical centre proceeds straight.

Q.131. *A lens made of glass has an object placed in air. The image is formed in water. Are the two principal focal lengths equal ? Explain.* (2)

Ans. No. The object space is air and image space is water. Let μ_1 and μ_2 be refractive index of object and image space respectively. If f_1 and f_2 is the first and second principal focal length of lens, then

$$\frac{\mu_2}{f_2} = -\frac{\mu_1}{f_1}$$

Since $\mu_1 \neq \mu_2$; $|f_1| \neq |f_2|$.

Q.132. *For refraction of light at a spherical surface, what is the interpretation of the positive or negative sign of u and v in the co-ordinate convention of signs ?* (1)

Ans. The negative sign of u indicates real object. The positive sign of u indicates a virtual object. The negative sign of v means virtual image. The positive sign of v means real image.

Q.133. *Write down the formula for refraction at a thin lens.* (1)

Ans. Let the refractive index of object and image space be same. The thin lens formula is,

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

u = object position, v = image position, f = focal length of lens.

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Q.134. *Write down the lens maker's formula.* **(1)**

Ans. According to lens maker's formula

$$\frac{1}{f}=\left(\frac{\mu_2}{\mu_1}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

R_1 and R_2 are the radii of curvature of lens surfaces, μ_2 is refractive index of lens material and μ_1 is refractive index of object and image space.

Q.135. *Usually, a convex lens is known as a converging lens and a concave lens as a diverging lens. Explain .* **(2)**

Ans. Let a parallel beam of light be incident on a convex lens [Refer to fig. (a) Q.No. 128 a] The refracted beam is a convergent beam, converging towards point F. Therefore, a convex lens is known as a convergent lens.

Fig. (b) of Q. No. 128, shows a parallel beam incident on a concave lens. The refracted beam is divergent. It appears to diverge from a point F on principal axis. Since the refracted rays constitute a divergent beam, concave lens in known as a divergent lens.

Q.136. *Show that a convex glass lens placed in air acts as a convergent lens.* **(2)**

Ans. Let μ be refractive index of material of convex lens. According to Lens maker's formula, the focal length (f) of lens is

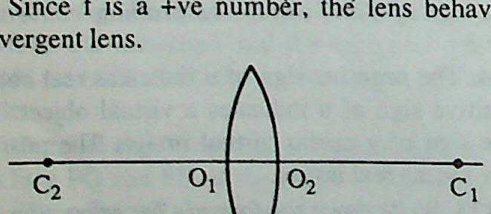
$$\frac{1}{f}=(\mu-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

$R_1 = +c$ = radius of curvature of first surface of lens .

$R_2 = -d$ = radius of curvature of second surface of lens

$$\frac{1}{f}=(\mu-1)\left(\frac{1}{c}+\frac{1}{d}\right)>0$$

Since f is a +ve number, the lens behaves as a convergent lens.

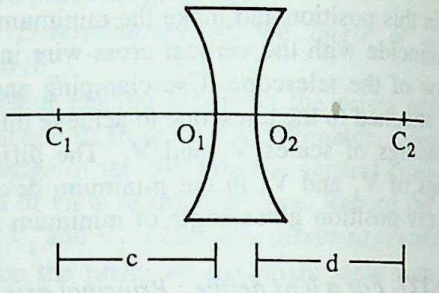


Q.137. *Show that a concave glass lens placed in air acts as a diverging lens.* **(2)**

Ans. Fig. below shows a concave glass lens (refractive index μ) placed in air. According to lens maker's formula,

$$\frac{1}{f}=(\mu-1)\left[\frac{1}{R_1}-\frac{1}{R_2}\right]$$

From fig. using coordinate convention of signs



$$R_1=-c,\ R_2=+d$$

$$\therefore \frac{1}{f}=-(\mu-1)\left(\frac{1}{c}+\frac{1}{d}\right)$$

$\therefore$ f is a –ve number. The negative value of f means that lens behaves as a diverging lens.

Q.138. *For a mirror, the focal length $f = R/2$ where R is the radius of curvature. What is the refractive index of an equal convex lens so that the above relation holds for lens also?* **(2)**

Ans. Let $R_1 = +c$ and $R_2 = -c$ be the radii of curvature of the two surfaces of an equi convex lens. From lens maker's formula,

$$\frac{1}{f}=(\mu-1)\left(\frac{1}{c}+\frac{1}{c}\right)=\frac{2(\mu-1)}{c}.$$

where μ is refractive index of lens material.

We want f = c/2. Therefore,

$$\frac{c}{2}=\frac{c}{2(\mu-1)}$$

or $\mu - 1 = 1$ or $\mu = 2$.

Q.139. *For paraxial rays, prove the relation*

$$\frac{\mu_2}{v}-\frac{\mu_1}{u}=\frac{\mu_2-\mu_1}{R}$$ **(3)**

Ans. In fig. below AOB is convex surface separating medium 1 and medium 2. The refractive index of the two media is μ_1 and μ_2 respectively. P is a point object at a distance OP = a, from the pole O of the refracting surface. PQ is a paraxial ray incident at point R of the spherical surface and RQ is the refracted ray. Q is the image of point object P due to

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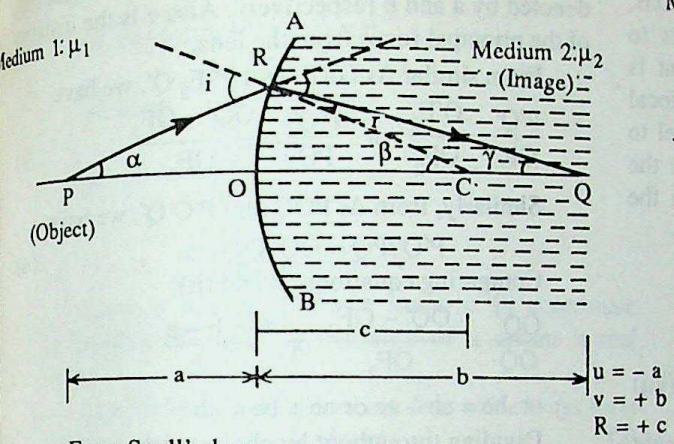
refraction at the convex surface. In Fig. $\mu_2 > \mu_1$, so that r < i.



From Snell's law,

$$\mu_1 \sin i = \mu_2 \sin r \text{ or } \mu_1 i \approx \mu_2 r \quad ...(i)$$

From Δ PRC; $i = \alpha + \beta$ ...(ii)

and from ΔCRQ, $\beta = r + \gamma$ or $r = \beta - \gamma$ ...(iii)

From eqns (i), (ii) and (iii)

$$\mu_1 (\alpha+\beta) = \mu_2 (\beta - \gamma)$$

or $$\mu_1 \alpha + \mu_2 \gamma = (\mu_2 - \mu_1) \beta \quad ... (iv)$$

For paraxial rays,

$$\alpha = \frac{OR}{OP};\ \beta = \frac{OR}{OC} \text{ and } \gamma = \frac{OR}{OQ}$$

From eqns (iii) and (iv) we have

$$\frac{\mu_1}{OP} + \frac{\mu_2}{OQ} = \frac{\mu_2 - \mu_1}{OC} \text{ or } \frac{\mu_1}{a} + \frac{\mu_2}{b} = \frac{\mu_2 - \mu_1}{c} \quad ...(v)$$

According to co-ordinate convention of signs,

$$u = -a,\ v = +b \text{ and } R = +c.$$

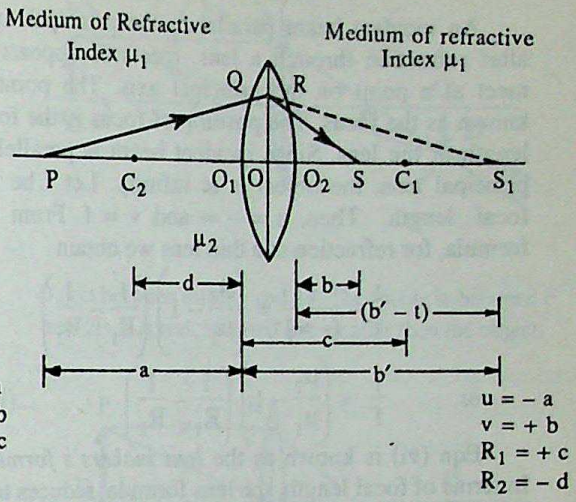
Therefore,

$$\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R} \quad ...(vii)$$

Eqn (vii) is the desired refraction formula.

Q.140. *Obtain Lens maker's formula* $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ **(3)**

Ans. Fig. below shows a convex lens of a material having refractive index μ_2 placed in a medium of refractive index μ_1. C_1 and C_2 are the centre of curvature of two lens surfaces. P is a point object placed at a distance OP = a on the principal axis. PQ is a ray incident at point Q on the first lens surface. The refracted ray is QR. Had there been no second lens surface, the refracted ray QR would meet principal axis at point S_1. Obviously, S_1 is image of P formed by refraction at first lens surface. For refraction at Q, according to co-ordinate convention signs,



$$u = -a,\ v' = +b',\ R_1 = +c$$

Applying refraction formula, we have

$$\frac{\mu_2}{(+b')} - \frac{\mu_1}{(-a)} = \frac{\mu_2 - \mu_1}{(+c)} \quad ...(i)$$

The ray QR is incident on the second lens surface. The final refracted ray RS meets principal axis at S. Therefore, S is image of point object P, due to refraction at both lens surface. For refraction at second lens surface S_1 acts as a virtual object producing a real image at S. According to co-ordinate convention of signs

$$u' = (b' - t),\ v = +b \text{ and } R_2 = -d$$

Here, t is the thickness of lens. Applying refraction formula at second lens surface, we get

$$\frac{\mu_1}{(+b)} - \frac{\mu_2}{(b'-t)} = \frac{\mu_1 - \mu_2}{(-d)} \quad ...(ii)$$

For a thin lens, t < a, and b, so that eqn (ii) reduces to

$$\frac{\mu_1}{b} - \frac{\mu_2}{b'} = \frac{\mu_1 - \mu_2}{(-d)} \quad ...(iii)$$

From eqns (i) and (iii);

$$\frac{\mu_1}{b} + \frac{\mu_1}{a} = \frac{\mu_2 - \mu_1}{c} + \frac{(\mu_1 - \mu_2)}{(-d)} \quad ...(iv)$$

For a thin lens if u and v refer to object and image position, according to co-ordinate convention of signs, u = –a and v = b

Eqn (iv) can be rewritten as

$$\frac{\mu_1}{v} - \frac{\mu_1}{u} = (\mu_2 - \mu_1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \quad ...(v)$$

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or $$\frac{1}{v}-\frac{1}{u}=\left(\frac{\mu_2}{\mu_1}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right) \quad ...(vi)$$

An incident beam parallel to the principal axis, after refraction through a lens, meets or appears to meet at a point on the principal axis. The point is known as the focus. The position of focus is the focal length of the lens. Since incident beam is parallel to principal axis, the object is at infinity. Let f be the focal length. Then, $u = -\infty$ and $v = f$. From the formula, for refraction at a thin lens we obtain

$$\frac{1}{f}-\frac{1}{(-\infty)}=\left(\frac{\mu_2}{\mu_1}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

or $$\frac{1}{f}=\left(\frac{\mu_2}{\mu_1}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right) \quad ...(vii)$$

Eqn (vi) is known as the *lens makers's formula.* In terms of focal length, the lens formula, reduces to

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}.$$

Q.141. *For a thin lens placed in air having an object of final size placed on the principal axis show that*

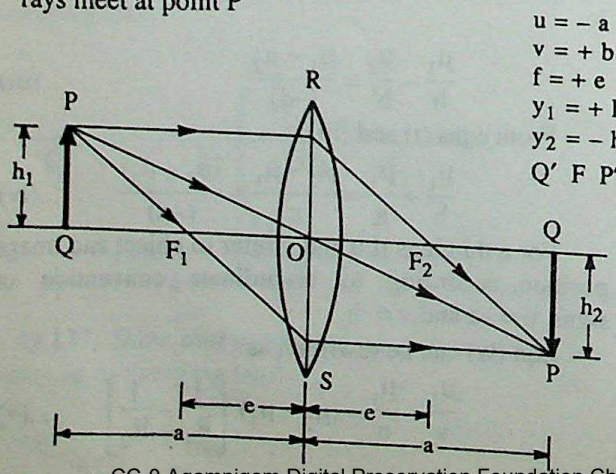
$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f} \qquad \textbf{(3)}$$

Ans. Let PQ be an object placed at right angles to the principal axis and at a distance OQ = a from the lens. To locate the image P′Q′ we consider the following rays :

(i) An incident ray PR parallel to the principal axis. The refracted ray RP′ passes through the focus F_2.

(ii) An incident ray PF_1 passing through focus. The refracted ray SP′ is parallel to principal axis.

(iii) An incident ray PO passing through the optical centre proceeds straight as OP′. The refracted rays meet at point P′



PQ be the image of object PQ, formed by convex lens. The ray diagram is shown in Fig. Let the distance of the object and image from the lens denoted by a and b respectively. Also e is the distance of the principal focus from the lens.

From similar Δs ORF_2 and $P'F_2Q'$, we have

$$\frac{P'Q'}{OR}=\frac{Q'F_2}{OF_2} \quad \text{or} \quad \frac{P'Q'}{PQ}=\frac{OQ'-OF_2}{OF_2}$$

Similarly, from Δs POQ and P′O Q′, we have

$$P'Q'/PQ = OQ'/OQ$$

Comparing equations (i) and (ii)

$$\frac{OQ'}{OQ}=\frac{OQ'-OF_2}{OF_2} \quad \text{or} \quad \frac{b}{a}=\frac{b-e}{e}$$

or be = ab – ae or ae + be = ab

Dividing throughout by abe, we get

$$\frac{1}{a}+\frac{1}{b}=\frac{1}{e}$$

This is the relation between the object and image distances. In terms of object and image positions according to the coordinate convention of signs, we have u = – a, v = +b, f = + e, so that eqn. (iii) becomes

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$$

Eqn (iv) represents the lens formula.

Q.142. *A convex lens is forming a virtual image of a real object. Show that the object lies between the focus and pole of the lens.*

Ans. Let a be distance of real object from lens. According to coordinate convention of signs u = –. Let b be distance of virtual image formed from lens. According to coordinate convention of signs v = +. Let f = +e the focal length of convex lens. According to lens formula,

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$$

or $$\frac{1}{(-b)}-\frac{1}{(-a)}=\frac{1}{e}$$

or $$\frac{1}{a}=\frac{1}{e}+\frac{1}{b}$$

or $$a=\frac{eb}{(b+e)}<e$$

Since the distance of object from lens is less than the distance of focus from it, the object lies in between focus and pole.

Q.143. *A real object is placed anywhere beyond the focus of a convex lens. Show that the image formed by the lens is real.*

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Ans. Let a be distance of real object from lens. According to coordinate convention of signs u = –a. Since object is placed beyond focus a > e. Also f = +e

From lens formule $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

we have $\frac{1}{v} - \frac{1}{(-a)} = \frac{1}{e}$

or $\frac{1}{v} = \frac{1}{e} - \frac{1}{a}$

or $v = \frac{ae}{(a-e)}$

Since a > e; v is a +ve number. In coordinate convention of signs, a +ve sign of v means a real image.

Q.144. *Show that a concave lens will always form a virtual image of a real object.* **(2)**

Ans. Let *a* be distance of real object from concave lens of focal length *e*. According to coordinate convention of signs

$$v = -a, \quad f = -e$$

From lens formula, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$, we have

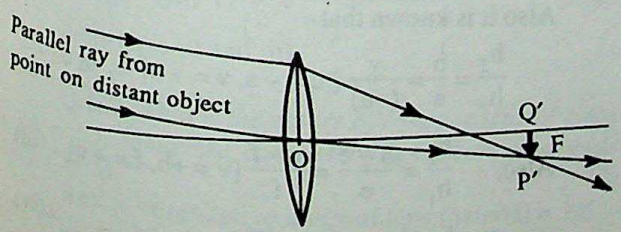
$$\frac{1}{v} - \frac{1}{(-a)} = \frac{1}{(-e)}$$

or $\frac{1}{v} = -\frac{1}{a} - \frac{1}{e}$ or $v = -\frac{ae}{(a+e)}$

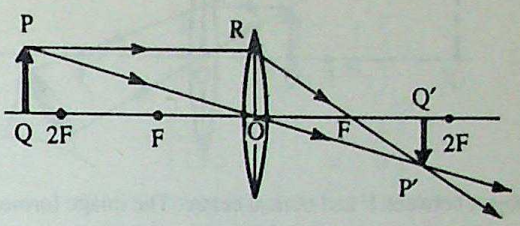
Since v is a negative number irrespective of value of a, the image formed is virtual.

Q.145. *Draw ray diagrams showing the image formed due to refraction at a convex lens as the object is moved from infinity towards the lens.* **(3)**

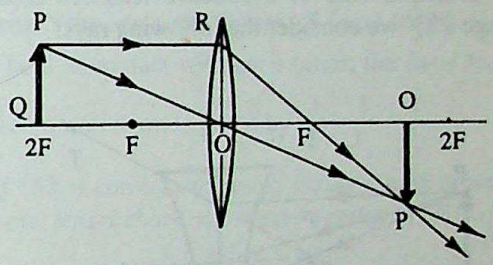
Ans. Following figures show the image formed by a convex lens when an object PQ is moved from infinity towards the lens. In all these diagram PR is an incident ray parallel to the principal axis. After refraction this ray passes through the focus F and proceeds as ray RF. Similarly OP is an incident ray passing through optical centre and, hence, proceeds straight.



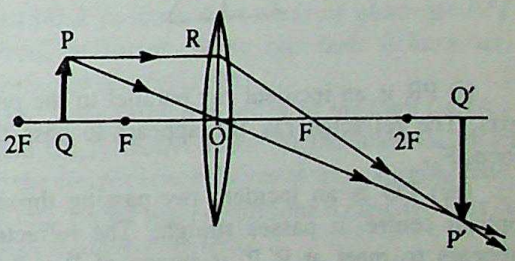
Object at infinity. The image at F is real, inverted and smaller in size



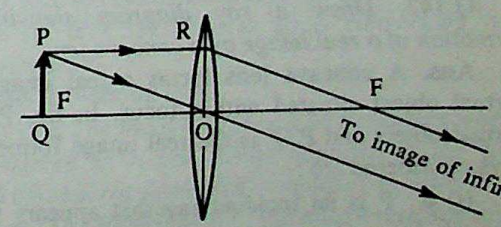
Object between infinity and 2F. The image is between F and 2F. It is real, inverted and smaller than the object.



Object at 2F. The image is also at 2F. It is real, inverted and of the same size as the object.



Object between F and 2 F. The image is formed beyond 2F. It is real, inverted and larger in size than the object..



Object at F. The image is formed at infinity.

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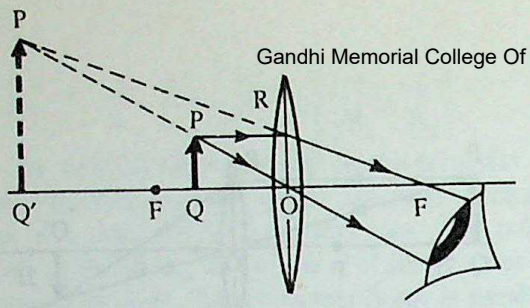
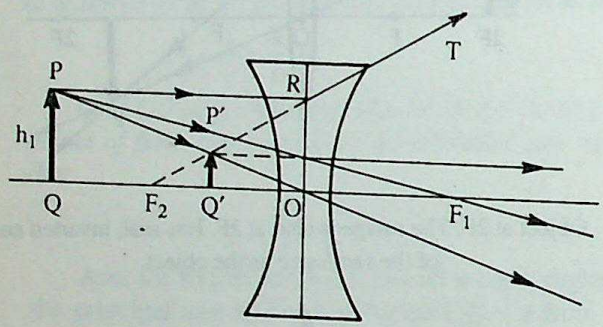


Object between F and optical centre. The image formed is virtual, erect and larger in size than the object.

Q.146. *Draw a ray diagram showing the formation of image of an object of finite size by a concave lens.* **(2)**

Ans. Fig. below shows an object PQ placed on the principal axis of a concave lens. To locate the image P′Q′ we consider the following rays:



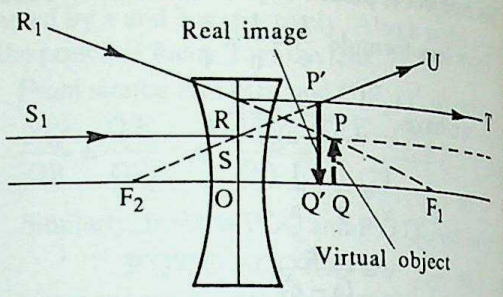
(i) PR is an incident ray parallel to the principal axis. The refracted ray RT appears to pass through focus F_2.

(iii) PO is an incident ray passing through the optical centre. It passes straight. The refracted rays appears to meet at P′.P′ is image of P and P′Q′ is image of object PQ, due to refraction at a concave lens. The image formed is virtual, erect and diminished.

Q.147. *Draw a ray diagram showing the formation of a real image by a concave lens.* **(2)**

Ans. A concave lens forms a real image of a virtual object situated within focus. In fig. PQ is a virtual object and P′Q′ is the real image formed. The rays considered are :

(i) R_1 P is an incident ray that appears to pass through focus F_1 and point P of virtual object. The refracted ray RT is parallel to principal axis. (ii) Ray S_1S is parallel to principal axis and appears to come from point P. The refracted ray SU appears to pass through F_2.



The two refracted rays meet at P′. P′ is the image of point P formed by concave lens. P′Q′ is the real image of virtual object PQ formed by the concave lens.

Q.148. *What is magnification ? What is the interpretation of the positive or negative sign of magnification ?* **(2)**

Ans. The ratio of the size of the image and the object is called magnification, i.e,

$$m = \frac{\text{Size of the image}}{\text{Size of the object}}$$

A positive sign of m means an erect image. The negative sign of m indicates an inverted image.

Q.149. *Obtain an expression for magnification.* **(3)**

Ans. The magnification m is defined as;

$$m = \frac{\text{Size of the image}}{\text{Size of the object}} = \frac{y_2}{y_1} \quad ...(i)$$

The magnification as defined in eqn (i) has a magnitude and sign. The magnitude gives the ratio of the length of the image and object, whereas the sign tells whether the image is erect or inverted. A -ve sign with m indicates an inverted image, whereas a +ve sign with m indicates an erect image. Let h_1 and h_2 be the length of the object and image. Then, according to the coordinate convention, the size of object and image, i.e., y_1 and y_2, is $y_1 = +h_1$, $y_2 = -h_2$ ...(ii)

$$\therefore \quad m = -h_2/h_1$$

Also it is known that

$$\frac{h_2}{h_1} = \frac{b}{a} = \frac{v}{(-u)} \; [u = -a, v = +b] \quad \therefore m = \frac{-v}{u}$$

Also, $$\frac{h_2}{h_1} = \frac{b-e}{e} = \frac{v-f}{f} \; [v = +b, f = +e] \quad ...(iii)$$

$$\therefore \quad m = h_2/h_1 = (f - v)/f \quad ...(iv)$$

Q.150. *An equi-convex lens is cut into two halves by a plane (i) XOX′ and (ii) YOY′, as shown in figure*

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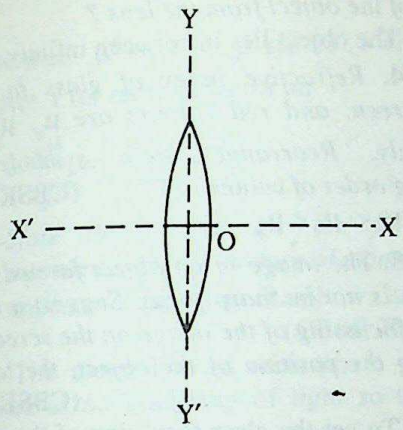
In each case what is the ratio of focal length of each half to the focal length of complete lens? **(2)**



Ans. Let c be the radius of curvature of each surface of the equi-convex lens. The focal length f of the lens, according to Lens maker's formula is

$$\frac{1}{f} = (\mu - 1)\left[\frac{1}{c} + \frac{1}{c}\right] = \frac{2(\mu - 1)}{c} \quad ...(i)$$

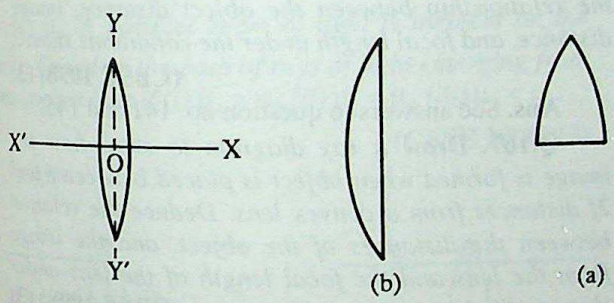


Fig. (a) shows one half of lens obtained, when it is cut by the plane XOX'. The radii of curvature of the two lens surfaces is same. Hence, f' = f or f' / f = 1

(ii) Fig. (b) shows one half of the lens obtained, when the lens is cut by plane YOY'.Now one lens surface is plane. Obviously $R_1 = +c$, $R_2 = -\infty$. The focal length f is

$$\frac{1}{f''} = (\mu - 1)\left(\frac{1}{c} + \frac{1}{\infty}\right) = \frac{(\mu - 1)}{c} \quad ...(ii)$$

From eqns (i) and (ii)

$$f''/f = 2$$

Q.151. *What is the nature of concave lens of glass (μ = 1.5) immersed completely in carbon-bisulphide (μ =1.65) ?* **(2)**

Ans. μ_2 = refractive index of lens material = 1.5.

μ_1 = refractive index of medium in which lens is placed = 1.65.

$R_1 = -c$ = radius of curvature of first lens surface.

$R_2 = -d$ = radius of curvature of second lens surface. According to lens maker's formula,

$$\frac{1}{f} = \left(\frac{\mu_2}{\mu_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$= \left(\frac{1.5}{1.65} - 1\right)\left(-\frac{1}{c} - \frac{1}{d}\right)$$

$$= \frac{0.15}{1.65}\left(\frac{1}{c} + \frac{1}{d}\right).$$

Obviously, f is a positive number. This means that lens behaves as a convergent lens.

Q.152. *Obtain an expression for the equivalent focal length of two thin lenses in contact.* **(3)**

Ans. When two this lenres of focal length f_1 and f_2 are held in contact with each other, the focal length F of the combination is given by $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$.

Q.153. *A convex air lens is inside a tank of water. Does the lens behave as a converging or diverging lens?* **(1)**

Ans. Since the refractive index μ_1 = 1.33 of material (water) in which lens is placed is more than the refractive index μ_2 = 1 of lens material (i.e., air), the convex lens will behave as a diverging lens.

Q.154. *A concave lens made of glass (μ=1.5) is immerred in water. Does the lens behave as a converging or diverging lens ?* **(1)**

Ans. Since refractive index of medium (water) is less than the refractive index of the material of lens (glass) the convex lens behaves as a converging lens.

Q.155. *Under what conditions a concave lens can behave as a converging lens?* **(1)**

Ans. When it is placed in a medium having refractive index more than the refractive index of the lens material.

Q.156. *A convex air bubble trapped in a tank of water (μ = 1.33) behaves as a converging or a diverging lens.* **(1)**

Ans. Diverging lens.

Q.157. *The focal length of a lens changes when it is immersed in water. What happens to the focal length of a mirror immersed completely in water?* **(1)**

Ans. The focal length of the mirror remains same.

Q.158. *A concave mirror and a concave lens are held in water. What changes, if any, do you expect in their respective focal lengths as compared to their values in air?* **[C.B.S.E. 1995] (2)**

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Ans. The focal length of the concave mirror remains same when it is immersed in water.

The focal length of the concave lens increases when it is immersed in water.

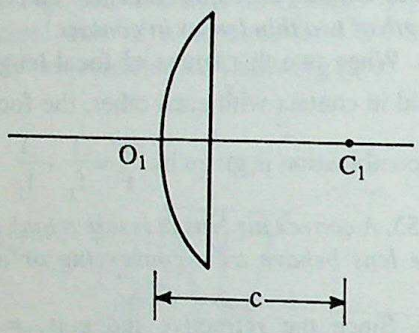
Q.159. *A plano convex lens is made of glass (μ = 1.5). What is the relation between the focal length and radius of curvature ?* (1)

Ans. Fig. below shows the plano-convex lens,

R_1 = radius of curvature of first surface of lens = + c

R_2 = radius of curvature of second surface of lens = ∞

μ = refractive index of lens material = 1.5



From lens maker's formula

$$\frac{1}{f} = (1.5 - 1)\left(\frac{1}{c} - \frac{1}{\infty}\right)$$

$$= \frac{0.5}{c} = \frac{1}{2c}$$

$$\Rightarrow \quad f = 2c$$

Q.160. *A convex lens forms a real inverted and enlarged image of an object. Where is the object placed ?* (1)

Ans. In between 2 F and F.

Q.161. *A convex lens has a focal length of 40 cm. An object is placed at a distance of 25 cm from the lens. What is the nature of image formed by refraction at lens ?* (1)

Ans. Since the object is placed within the focus and pole of the lens, the image formed is virtual, erect and magnified.

Q.162. *A real inverted image equal in length to the object is obtained on a screen by using a convex lens. If focal length of lens is 25 cm, what is the distance of object and screen from the lens ?* (1)

Ans. The distance of the object and the image from lens = 2 f, where f is focal length of the lens. Given f =25 cm. Therefore, distance of object and screen from lens equals 50 cm.

Q.163. *A real, diminished and inverted image of an object is formed by a convex lens. What is the distance of the object from the lens ?* (1)

Ans. The object lies in between infinity and 2F.

Q.164. *Refractive index of glass for light of yellow, green, and red colours are μ_y, μ_g, and μ_r respectively. Rearrange these symbols in an increasing order of values.* (CBSE 1997) (1)

Ans. $\mu_r < \mu_y < \mu_g$

Q.165. *The image of an object formed by a lens on screen is not in sharp focus. Suggest a method to get clear focussing of the image on the screen without disturbing the position of the object, the lens or the screen.* (CBSE 1998) (1)

Ans. To get the clear focussing of the image, the focal length of the lens can be changed by placing another lens of suitable fotal length in contact with the previous lens.

Q.166. *Draw a ray diagram to show the formation of the image of an object placed between the optical centre and focus of a convex lens. Deduce the relationship between the object distance, image distance, and focal length under the conditions stated.* (CBSE 1998) (3)

Ans. See answers to question no. 141 and 145.

Q.167. *Draw a ray diagram to show how the image is formed when object is placed between f and 2f distances from a convex lens. Deduce the relation between the distances of the object, and the image from the lens and the focal length of the lens under this condition.* (CBSE 1998) (3)

Ans. See answers to questions no 141 and 145.

Q.168. *A concave mirror and a convex lens are held separately in water. What changes, if any, do you except in the focal length of either?.* (CBSE 2000) (2)

Ans. Focal length of concave mirror remains the same when immersed in water. From lens maker's formula, it is found that focal length of convex lens under water increases because ${}^{w}\mu_g < {}^{a}\mu_g$.

Q.169. *State the conditions for total internal reflection of light to take place at an interface separating two transparent media. Hence, derive the expression for the critical angle in terms of the speed of light in the two media.* (CBSE 2000) (3)

Ans. Conditions for total internal reflection are:

(i) Light should travel from a denser medium to rarer medium.

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(ii) Angle of incidence in denser medium should be greater than the critical angle for the pair of media in contact.

We know that ${}_a\mu^d \sin i_c = {}_a\mu^r \sin 90°$, where, d stands for denser, r for rarer and a for air.

$$\text{or } \sin i_c = \frac{{}_a\mu^r}{{}_a\mu^d} = \frac{c_a}{c_r} \Big/ \frac{c_a}{c_d} = \frac{c_d}{c_r}.$$

Q.170. *State the reason for the following observations recorded from the surface of moon.*

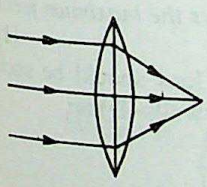
(i) Sky appears dark. (ii) Rainbow is never formed. **(CBSE 2000) (2)**

Ans. (i) The moon has no atmosphere or dust particles. There is no scattering of light so the sky appears dark.

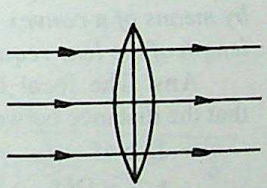
(ii) There are no water vapours on the moon. Hence, there is neither dispersion nor total internal reflection of sun rays. Consequently, rainbow is never observed in the moon.

Q.171. *A convex lens made of a material of refractive index μ_1 is kept in a medium of refractive index μ_2. A parallel beam of light is incident on the lens. Complete the path of rays of light emerging from the convex lens if (i) $\mu_1 > \mu_2$ (ii) $\mu_1 = \mu_2$ (iii) $\mu_1 < \mu_2$.* **(CBSE 2000) (3)**

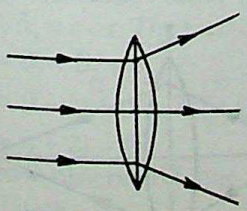
Ans.



(i) $\mu_1 > \mu_2$



(ii) $\mu_1 = \mu_2$



(iii) $\mu_1 < \mu_2$

Q.172. *Write two essential conditions for total internal reflection to take place in a transparent medium. Give two examples of this phenomenon in daily life situations.* **(CBSE 1998) (2)**

Ans. See answer to question 169 for 1st part.

(i) The brilliance of dimond is due to total internal reflection of light.

(ii) Mirages are due to total internal reflection.

Q.173. *Violet light is incident on a converging lens of focal length f. State with reasons how focal length of the lens will change, if the violet light is replaced by red light.* **(CBSE 1999) (2)**

Ans. We know that $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

Also, $\mu_{red} < \mu_{violet}$

$\therefore \frac{1}{f_{red}} < \frac{1}{f_{violet}}$

$\Rightarrow f_{red} > f_{violet}$

Hence, the focal length will increase.

Q.174. *Define the power of lens.* **(1)**

Ans. The reciprocal of focal length expressed in meter is the power of the lens.

$$\text{Power, } P = \frac{1}{f \text{ (in meter)}}$$

Q.175. *What is the unit of the power of lens ?* **(1)**

Ans. Diopter

Q.176. *A glass lens of power –5D is completely immersed in water. Does the power of the lens increase or decrease ? Explain.* **(2)**

Ans. When the lens is immersed in water the focal length of lens increases. The power of lens is inversely proportional to focal length, therefore, the power of lens decreases.

Q.177. *A lens has a focal length of – 50 cm. What is the nature and power of the lens ?* **(1)**

Ans. Since f is negative, the lens is a concave lens. Also f = -50 cm = – 0.5m, therefore,

$$P = \frac{1}{-0.5} = -2D.$$

Q.178. *A convex lens has a focal length of 25 cm. What is the power of the lens ?* **(1)**

Ans. Given f = +25 cm = 0.25 m, therefore,

$$P = \frac{1}{f} = \frac{1}{0.25} = +4D.$$

Q.179. *The power of a lens is –2D. What is the focal length and nature of the lens ?* **(1)**

Ans. Since power of lens is negative it is concave lens.

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Also $P = -2 = \frac{1}{f}$ or $f = -\frac{1}{2}$ m $= -0.5$ m $= 50$ cm.

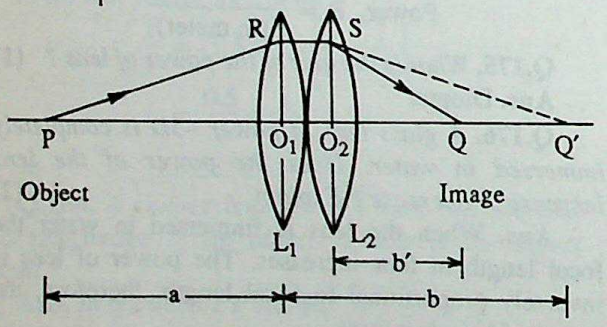
Q.180. *Sun glasses (goggles) generally have curved surface but they do not have any power. Why??* **(2)**

Ans. Both the surfaces of sun glasses (goggles) have same nature and radius of curvature, i.e., $R_1 = R_2$ The power P, is

$$P = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = 0$$

Q.181. *Obtain an expression for equivalent focal length of two thin lens in contact. Two thin lenses of power +5D and –3D are in contact. What is the power of the combination ?* **(5)**

Ans. Let L_1 and L_2 be two thin lenses of focal length f_1 and f_2 respectively placed co-axially and in contact with one another. P is a point object on the principal axis of the system. An incident ray PR, after refraction from lens L_1 proceeds along direction RS. It would have met principal axis at Q_1 , had there been no lens L_2. We can say Q_1 is image of object P formed by lens L_1. Obviously, from fig. applying the formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f_1}$, we get,



$$\frac{1}{b} + \frac{1}{a} = \frac{1}{f_1} \quad ...(i)$$

The ray RS acts as incident ray for lens L_2 and forms a final image at Q. For lens L_2, Q′ acts as a virtual object producing a real image Q. Clearly, for second lens L_2

$u = +b$ [+ve sign because it is a virtual object]

$v = +b$ [+ve sign because it is a real image]

Applying lens formula to L_2 we obtain

$$\frac{1}{b'} - \frac{1}{b} = \frac{1}{f_2} \quad ...(ii)$$

Add equation (i) and (ii). Therefore,

$$\frac{1}{b'} + \frac{1}{a} = \frac{1}{f_1} + \frac{1}{f_2}$$

or $$\frac{1}{v} - \frac{1}{u} = \frac{1}{f_1} + \frac{1}{f_2} \quad ...(iii)$$

Equation (iii) suggests that we can replace the combination of two lenses by a single thin lens of focal length F such that

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{F} \quad ...(iv)$$

Obviously, from equation (iii) and (iv)

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} \quad ...(v)$$

F in eqn (v) is known as the *equivalent focal length* of the combination. In terms of *power* of a lens eqn (v) can be rewritten very conveniently. If P is the equivalent power of the lens combination by definition

$$\frac{1}{F} = P \text{ and } \frac{1}{f_1} = P_1 ; \frac{1}{f_2} = P_2 \quad ...(vi)$$

Therefore, $P = P_1 + P_2$

P = The power of combination of two thin lenses

$= P_1 + P_2$

Given $P_1 = 5$ D and $P_2 = -3$D

$\therefore P = 5 + (-3) = +2$D.

Q.182. *The image of an electric bulb fixed on a wall of the room is to be obtained on the opposite wall by means of a convex lens. What is the maximum focal length of the lens required ?* **(3)**

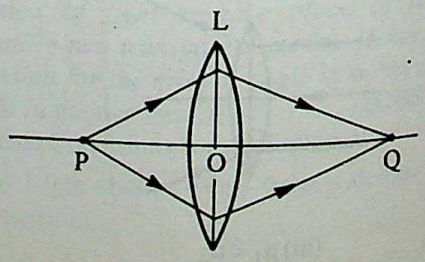
Ans. The focal length f of lens should be such that the distance between the two walls (D) is

$D \geq 4f$

$\therefore f_{max} = D/4$

Q.183. *A convex lens forms real image of a point object. Another lens is placed in between the convex lens and the image. The image formed by the combination is more far off the convex lens. What is the nature of the other lens ? Explain.* **(2)**

Ans. Concave lens fig. (a) shows the image Q of a real object P, formed due to convex lens L. L_1 is



(a)

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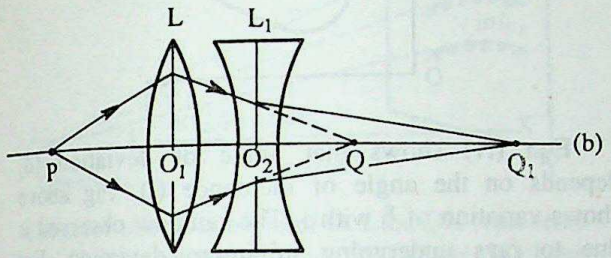
second lens placed in between L and Q. The final image is Q_1. For lens L_1, Q acts as a virtual object. Since the image formed is further away from the lens, the rays gets deviated away from principal axis. A concave lens bends rays away from principal axis. Therefore, lens L_2 is a concave lens.



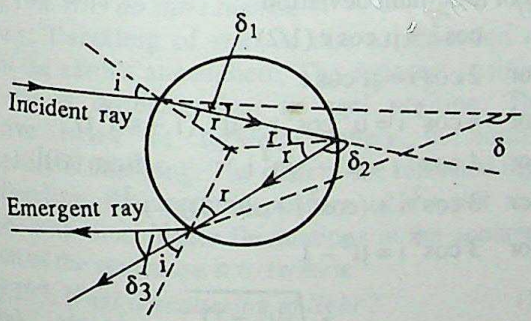
Q.184. *What is a rainbow ?* **(1)**

Ans. Rainbow is the dispersion of white sun light in a water drop.

Q.185. *In a clear ray diagram show the path of rays producing primary rainbow. Write an expression for an angle of deviation.* **(3)**

Ans. The primary rainbow is due to sun rays entering the upper half of a raindrop. The ray is incident at A at an angle i. Angle of refraction at A is r. The angle of deviation at A, $\delta_1 = i - r$. The ray AB is incident at B and undergoes a reflection (not total internal reflection). The angle of deviation at B,

$$\delta_2 = \pi - 2r.$$



Similarly, refraction takes place at C. The deviation at C, $\delta_3 = i - r$. The total deviation δ is

$$\delta = \delta_1 + \delta_2 + \delta_3$$
$$= (i - r) + (\pi - 2r) + (i - r)$$
$$= \pi + 2i - 4r.$$

The rainbow observed is due to rays undergoing minimum deviation.

Q.186. *What is the sequence of colours observed in a primary rainbow ?* **(1)**

Ans. In primary rainbow the inner edge is violet and the outer edge is red.

Q.187. *How many reflections and refractions occur for a ray producing primary rainbow ?* **(1)**

Ans. Two refractions and one reflection.

Q.188. *What angle does the radius of primary rainbow subtend at the observer's eye ?* **(1)**

Ans. The primary rainbow subtends an angle of 40° at the observer's eye.

Q.189. *What angle does the radius of secondary rainbow subtend at the observer's eye ?* **(1)**

Ans. The secondary rainbow subtends an angle of 52° at the observer's eye.

Q.190. *What are the colours at the inner and outer edge of a secondary rainbow ?* **(1)**

Ans. The inner edge is red and the outer edge is violet.

Q.191. *What basic phenomenon explain the formation of rainbow ?* **(1)**

Ans. Dispersion of light.

Q.192. *Give characteristic of primary rainbow.* **(2)**

Ans. (i) The innermost colour is violet and the outermost colour is red. The other colours in VIBGYOR lie in between.

(ii) The violet coloured arc subtends an angle of 40.8° at the eye of the observer.

(iii) The red coloured arc subtends an angle of 42.8° at the eye of the observer.

Q.193. *Explain why the rainbow observed is due to rays undergoing minimum deviation in rain drop.* **(2)**

Ans. The emergent rays are most intense in the direction of minimum deviation. A ray incident on raindrop at an angle of incidence for minimum deviation emerges out almost in same direction as the minimum deviated ray. For angle of incidence other than that for minimum deviation, the emergent rays emerge in widely different directions even for a small variation in angle of incidence. Therefore, intensity of emergent rays is maximum in the direction of minimum deviation.

Q.194. *Explain, why is rainbow observed in an arc of a circle.* **(2)**

Ans. In fig. below O is an observer. The incident ray moves along horizon or x-axis. The rain drops are present in Y-Z plane. O_1 is the projection of the line of sight of observer. The violet colour is due to rain drops that produce a deviation of 40.8°. With point O_1 as centre if we draw a circle such that cone angle at observer O is 40.8°, these rain drops produce violet colour minimum deviated ray. The drops lying along

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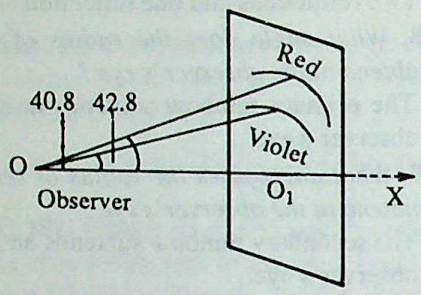
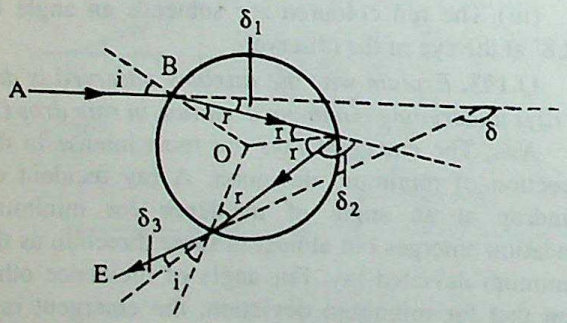
the circumference of this cone appear violet. Similarly, red coloured bow is due to raindrops making an angle of 42.8° with horizon. It is clear from fig. that the rainbow observed is an arc of a circle.



Q.195. *What is rainbow? Give a theory of the formation of primary rainbow. In what part of the sky rainbow is seen in the morning? In what order are the colours arranged and why ?* **(5)**

Ans. Rainbow is a natural phenomenon. It occurs, when sun starts shining brightly just after it has rained. Rainbow is produced due to dispersion of Sun's light in water drops. The primary rainbow is produced due to sun's rays undergoing one internal reflection in a rain drop. Fig. below shows an incident ray AB. It undergoes refraction at B.



The angle of deviation δ_1 at B is $\delta_1 = i - r$ ...(i)

The ray BC is incident at point C of rain drop and undergoes reflection The angle of deviation δ_2 at point C is

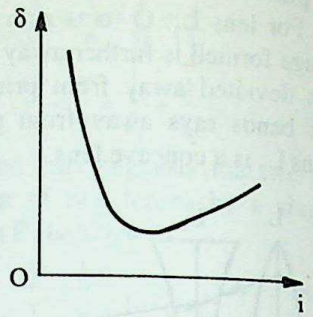
$$\delta_2 = \pi - 2r \quad ...(ii)$$

The ray CD undergoes refraction at point D and emerges out as DE. The deviation δ_3 at point D is

$$\delta_3 = i - r \quad ...(iii)$$

The total deviation δ is

$$\delta = \delta_1 + \delta_2 + \delta_3$$
$$= (i - r) + (\pi - 2r) + (i - r)$$
$$= \pi + 2i - 4r \quad ...(iv)$$



Eqn (iv) shows that angle of deviation (δ) depends on the angle of incidence (i). Fig above shows variation of δ with i. The rainbow observed is due to rays undergoing minimum deviation. For minimum deviation

$$\frac{d\delta}{di} = 0$$

or $$2 - \frac{4dr}{di} = 0$$

or $$\frac{dr}{di} = \frac{1}{2} \quad ...(v)$$

Applying Snell's law to refraction at point B

$$\sin i = \mu \sin r \quad ...(vi)$$

where μ is refractive index of water. Differentiation of erqn (vi) gives

$$\cos i = \mu \cos r \left(\frac{1}{2}\right) \quad [\text{from (v)}]$$

For minimum deviation

$$\cos i = \mu \cos r\ (1/2)$$

or $$2 \cos i = \mu \cos r$$

or $$4 \cos^2 i = \mu^2 \cos^2 r = \mu^2\ (1 - \sin^2 r)$$

or $$4 \cos^2 i = \mu^2 - \sin^2 i \quad [\text{from (vi)}]$$

or $$3 \cos^2 i + (\cos^2 i + \sin^2 i)) = \mu^2$$

or $$3 \cos^2 i = \mu^2 - 1$$

or $$\cos i = \sqrt{\frac{(\mu^2 - 1)}{3}} \quad ...(vii)$$

Eqn (vii) gives angle of incidence for which deviation is minimum. For red colour $\mu_R = 1.329$ $\therefore$ i = 59.6° and r = 40.5°. The angle of minimum deviation for red colour (δ_R) is

$$\delta_R = 180 + 2 \times 59.6 - 4 \times 40.5 = 137.2°$$

Therefore, the emergent red rays in primary rainbow make an angle of 180 – 137.2 = 42.8° with the horizon. Similarly, calculation for violet colour shown that the violet rays in primary rainbow make an angle of 40.8° with the horizon.

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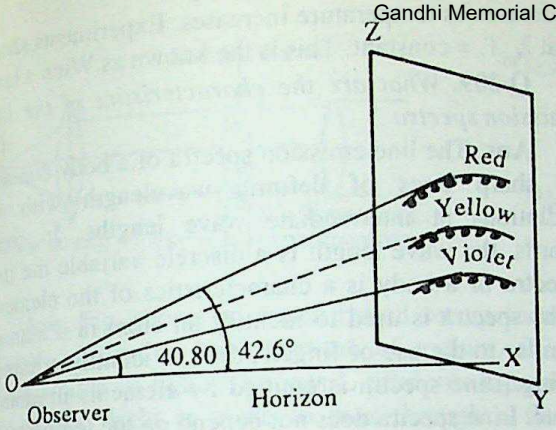


Consider observer at point O. Line OX represents horizon. Consider water drops in Y-Z plane. We have seen that the minimum deviated red rays subtend at an angle of 42.8° at eye of observer O. All rain drops lying along the circumference of a circle subtending an angle of 42.8° at O will produce red coloured minimum deviated ray. Therefore, these rain drops will appear red. This is a circular bow of red colour. Similarly, all rain drops lying along circumference of a circle subtending an angle of 40.8° at O produce minimum deviated violet coloured ray. This arc, therefore, appears violet. The other colours lie in between these extremes. The rainbow seen therefore, is semi–circular.

To see rainbow the observer must stand with his back towards Sun and look in the sky.

Q.196. *Why do stars twinkle ?* **(2)**

Ans. Twinkling of stars is due to refraction of light in the earth's atmosphere. The apparent position of a star is different than its real position. The refractive index of different layers in earth's atmosphere is changing. The path of the refracted rays and, therefore, the apparent position of the star also changes with time. These fluctuations in the apparent position of the star cause it to twinkle.

Q.197. *What is scattering of light ?* **(1)**

Ans. When radiations travelling through a transparent medium and the reflected rays move in different directions we say radiations have undergone scattering (or diffused reflection).

Q.198. *State Rayleigh's law of scattering.* **(1)**

Ans. According to Rayleigh's law, the intensity of light of wavelength λ present in scattered light is proportional to the fourth power of the wavelength, i.e.;

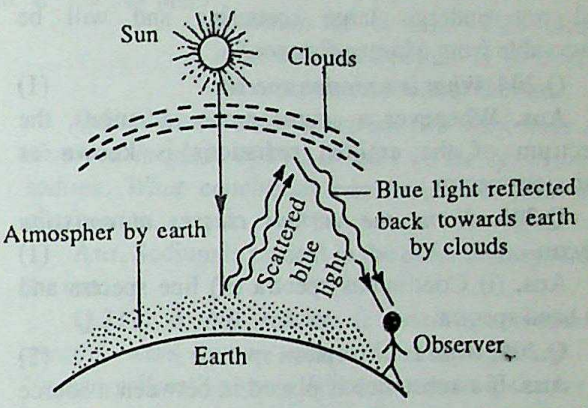
$$I \propto \frac{1}{\lambda^4}$$

Q.199. *Name a natural phenomenon which can be explained on the basis of Rayleigh's scattering.* **(1)**

Ans. Blue of sky

Q.200. *Explain, why sky appears blue.* **(2)**

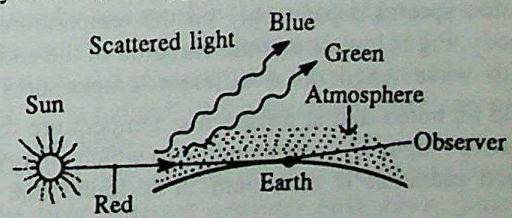
Ans.



The white light from the sun enters the atmosphere of earth and undergoes scattering therein. The wavelength of blue colour is small and according to Rayleigh's law, it is scattered most. The scattered blue rays move towards clouds as shown in fig above. The clouds reflect these blue rays back towards earth. The sky, therefore, appears to be bluish in colour.

Q.201. *Explain, why sun appears reddish at sunrise and sunset.* **(2)**

Ans. During sunrise or sunset the Sun's rays move as shown in fig. below. In the atmosphere of earth the red colour is scattered least, in accordance with Rayleigh's law. The red coloured rays reach the observer, whereas the other colours are scattered away. Hence, sun appears reddish in colour.



Q.202. *Why traffic lights used are red, orange and green in colour ?* **(2)**

Ans. For smooth movement of traffic, the traffic lights should be clearly visible from a long distance. The light undergoes scattering in air. According to Rayleigh, scattering is proportional to λ^{-4}. Since λ is maximum for red colour, it is scattered least and is visible clearly from a large distance. Since scattering is comparatively small for red, orange and green, these are colours used for traffic lights.

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Q.203. *Vehicles moving in foggy weather use yellow colours headlights. Why ?* **(2)**

Ans. In foggy weather scattering of light is large because more scatterers are present in air. Wavelength of yellow light is large (about 600 nm) and intense yellow source are easy to produce. The yellow light will not undergo large scattering and will be observable from a larger distance.

Q.204. *What is emission spectra ?* **(1)**

Ans. Whenever a source emits radiations, the spectrum of the emitted radiations is known as emission spectra.

Q.205. *Name the various classes of emission spectra.* **(1)**

Ans. (i) Continuous spectra (ii) line spectra and (ii) band spectra.

Q.206. *What is absorption spectra ?* **(1)**

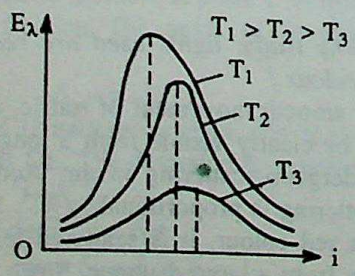
Ans. If a substance is placed in between a source and a spectrometer, the spectra of radiations emerging out of the substance is known as the absorption spectra.

Q.207. *Name the various classes of absorption spectra.* **(1)**

Ans. (i) Continuous, (ii) line and (iii) band spectra

Q.208. *List the characteristics of the continuous emission spectra.* **(2)**

Ans. In a continuos emission spectra the wavelength of emitted radiations is a continuous variable. In other words, all wavelength are present in the emitted radiation. The characteristics of continuous emission spectra do not depend on the nature of the body. The characteristics of continuous emission spectra depend only on the temperature of the body. Fig below. shows the variation of the energy E_λ with wave length λ at different temperatures. It should be noted that at a particular temperature there is a wave length λ_m corresponding to which energy of emitted radiation is maximum. It is found that λ_m decreases as temperature increases. Experiments show that $\lambda_m T$, = constant. This is the known as Wien's law

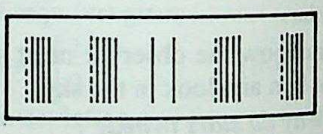


Q.209. *What are the characteristics of the line emission spectra ?* **(2)**

Ans. The line emission spectra of a body consists of sharp lines of definite wavelength with no radiations at intermediate wave lengths. In other words, the wave length is a discrete variable the line spectra of a body is a characteristics of the element. Line spectra is used to identify an atom in a manner similar to the use of finger-prints to identify a human being. Line spectra is emitted by elements in atomic state. Line spectra does not depend on the temperature of the element

Q.210. *What are the characteristics of band emission spectra ?* **(2)**

Ans. A band emission spectra consists of a number of bright bands separated from one another by dark regions as shown in fig. Within a band all values of wavelength are allowed. In between two bands no wavelength is allowed. One edge of each band is sharp, whereas the other edge fades gradually giving rise to a *flutted* appearance. Therefore, band spectra is also referred to as flutted spectra. Band spectra is emitted by substances in molecular state. It is a characteristic of the molecule.



Q.211. *Distinguish between emission and absorption spectra.*

Ans.

	Emisson spectra	Absorption spectra
(i)	It is due to radiations emitted from a body.	It is due to absorption of certain radiations by material placed in between source & spectrometer.
(ii)	The body producing emission spectrum is at a high temperature.	The body producing absorption spectrum is due to body at room temperature.
(iii)	Emission spectra consists of bright regions.	The absorption spectrum shows itself as dark regions.

Q.212. *Give an experimental set up to observe absorption spectrum. What are the characteristics of the absorption line spectra ?* **(3)**

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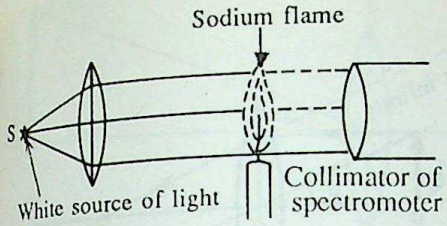

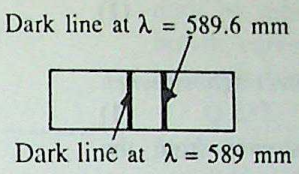

Ans. Fig. shows an experimental set up used to observe absorption line spectrum of sodium. S is a white source of light. The lens L produces a parallel beam. This light is made to pass through a flame having common salt sprinkled on it. In the flame sodium exists in atomic state. The transmitted light is collected by the collimator of a spectrometer and analysed. The spectrum of transmitted light has *two dark lines* having same wave length as that of D_1 and D_2 line in the emission spectrum of sodium as shown in fig. (b). These dark lines are the characteristics of absorption line spectrum of sodium. The absorption is again a characteristics of the element.

Q.213. *Usually, the characteristic line spectrum of atoms is compared to ''human finger prints''. Explain this statement.* **(2)**

Ans. We know that human beings can be identified on the basis of *''finger prints''* The finger prints of each individual are his (or her) characteristics. Finger prints of no two individuals are exactly same. Similarly, the line spectrum of an atom is a characteristics of the atom. The line spectrum of no two atoms can be exactly identical. Therefore, an atom can be identified on the basis of its characteristics line spectrum. Therefore, the characteristics line spectrum of atoms is compared to human finger prints.

Q.214. *What are Fraunhoffer's dark lines ? How are Fraunhoffer's dark lines produced?* **(2)**

Ans. Fraunhoffer's dark lines are dark lines observed in the absorption spectrum. The Fraunhoffer's dark lines are due to certain wavelengths emitted by the central visible disc of the sun having been absorbed by the atoms present in the outer atmosphere surrounding the sun.

Q.215. *Discuss the importance of Fraunhoffer's dark lines.* **(2)**

Ans. Fraunhoffer's dark lines are used to identify the elements that are present around the atmosphere of a planet or star. By compring the dark lines with the characteristic the emission spectra of various elements, we can find out the elements that are present in the atmosphere around the planet or star For example, the Fraunhoffer's dark lines in solar spectrum coincide with the D_1 and D_2 in the line emission spectrum of sodium. This clearly indicates that sodium is present in the outer atmosphere of the sun.

Q.216. *In the solar spectrum two dark lines are observed in place of two D lines in the spectrum of sodium. What conclusion can be drawn from this observation.* **(1)**

Ans. Sodium is present in the outer atmosphere of the sun.

Q.217. *A hot source is emitting continuous spectra with most intense wavelength in the ''green-yellow'' region. What is the temperature of the source ?* **(1)**

Ans. About 5000-6000 K.

Q.218. *A body X appears reddish in colour, whereas another body Y is yellowish red. Which of the two bodies is at higher temperature ?* **(1)**

Ans. Body Y is at a higher temperature than body X.

Q.219. *An unknown salt is sprinkled over the flame of a Bunsen burner. The flame acquires a yellow colours. What conclusion regarding nature of the salt can be drawn ?* **(1)**

Ans. The salt is of sodium.

Q.220. *Why a sodium vapour lamp is yellow in colour, whereas a neon lamp is reddish ?* **(2)**

Ans. The wavelength of the characteristic lines emitted by sodium is in the yellow region of spectrum; therefore, it has a characteristic yellow colour. However, the characteristic lines emitted by a neon lamp lie in red part of the spectrum, therefore, a neon lamp is reddish.

Q.221. *Why a domestic fluorescent tube produces white light, whereas ordinary bulb gives yellowish light?* **(2)**

Ans. The walls of domestic fluorescent tube are coated with a fluorescent material. The fluorescent material absorbs radiations emitted in the ultraviolet part and reemits this energy in the visible region. Therefore, fluorescent tube produces white light.

In an ordinary bulb the temperature of filament is such that maximum energy is emitted in the yellow part of the spectrum. Therefore, ordinary bulb appears yellowish.

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Q.222. *What is the range of wavelengths emitted by a hot electric iron ?* (1)

Ans. From 0 to ∞

Q.223. *What does a welder protect against when he wears a mask ?* (1)

Ans. The welder protects his eyes from the ultra-violet radiations emitted from the welding arc.

Q.224. *What is the colour of piece of glass when viewed in a dark room under a sodium lamp ?* (1)

Ans. Black.

Q.225. *What is angular magnification ?* (1)

Ans. The ratio of the angular size of image and object is known as angular magnification.

Q.226. *Is angular magnification same as linear magnification ?* (1)

Ans. No.

Q.227. *Define magnifying power.* (1)

Ans. The magnifying power of an optical instrument is the ratio of the angular size of the image and the object.

Q.228. *When an object is viewed through a magnifying glass, the eye is placed as close as possible to the lens. If the eye is moved away from the magnifying glass, does the angular magnification change ?* (1)

Ans. Yes. The angular magnification decreases as eye is moved far away from the magnifying glass.

Q.229. *The angle subtended at the eye by an object is equal to the angle subtended at the eye by the virtual image produced by a magnifying lens. In what sense then does a magnifying lens provide angular magnification ?* (2)

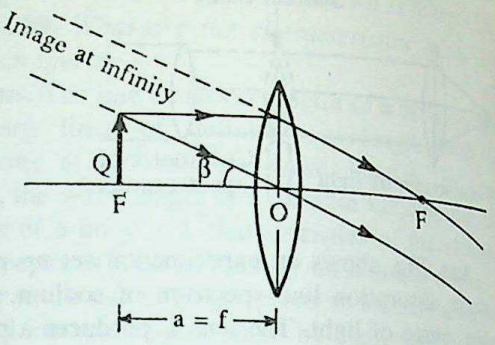
Ans. Without magnifying lens the object must be placed at least at a distance of 250 mm from eye. The object cannot be placed at a distance less than 250 mm. However, with a magnifying glass the object is placed nearer to eye at a distance much less than 250 mm. An object placed nearer to the eye has a longer angular size than an object placed at 250 mm from the eye. It is in this sense that magnification is achieved.

Q.230. *What is a simple microscope ?* (1)

Ans. A simple microscope is a short focal length convex lens. The object to be magnified is placed in between the focus and the pole of the lens.

Q.231. *Draw a ray diagram for simple microscope showing the formation of image at infinity.* (3)

Ans. Fig. below shows the objects to be magnified at the focus of the lens L. This final image is obtained at infinity.



Q.232. *What is magnifying power ? Discuss giving a ray diagram, a simple microscope. Show that its magnifying power is* $1 + \frac{D}{f}$, *where D is the distance of distinct vision.* (3)

Ans. A simple microscope or a magnifying glass is a short focal length convex lens. The object to be magnified is placed within the focus, so that a virtual, erect and magnified image is produced. The position of image depends on the position of the object. Consider an object so placed that image is formed at *distance of distinct vision.* Fig. below shows an object PQ placed with in the focus of lens L in such a manner that the image P′Q′ is formed at a distance of distinct vision D. Let the object be at a distance a from the lens L. Then u = –a, v = – D. From lens formula

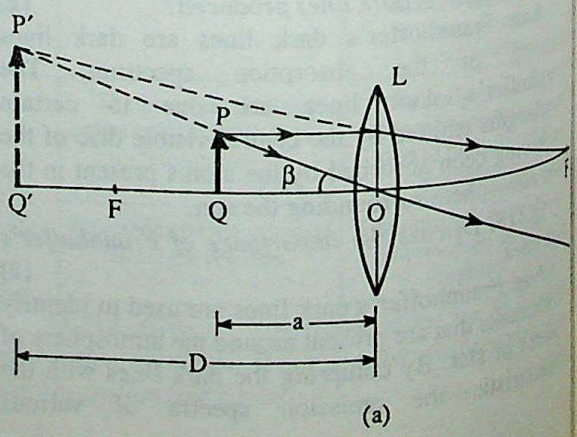
$$\frac{1}{(-D)} - \frac{1}{(-a)} = \frac{1}{f} \quad \text{or} \quad \frac{1}{a} = \frac{1}{f} + \frac{1}{D} \quad ...(i)$$

The angular size β of the image, from fig. is

$$\beta = \tan \beta = \frac{P'Q'}{OQ'} = \frac{PQ}{OQ} = \frac{PQ}{a} \quad ...(ii)$$

The angular size, α, of the object is obtained from fig. (b). Obviously,

$$\alpha = \tan \alpha = PQ/D \quad ...(iii)$$



(a)

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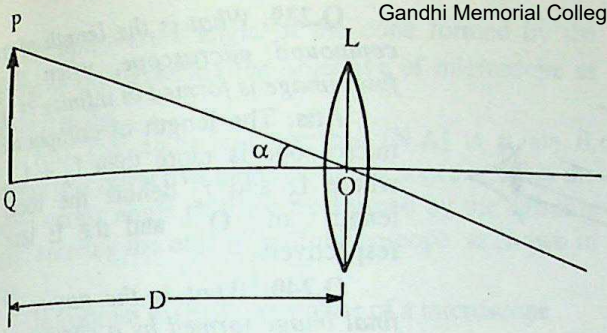


(b)

The magnifying power, M, by the definition is

$$M = \frac{\beta}{\alpha} = \frac{PQ}{a} / \frac{PQ}{D} = \frac{D}{a} \quad ..(iv)$$

From eqns (i) and (iv), we have

$$M = \frac{D}{f} + 1 \quad (v)$$

Q.233. *Write an expression for the magnifying power of a simple microscope.* **(1)**

Ans. The magnifying power of a simple microscope is $1 + \frac{D}{f}$, where D is distance of distinct vision and f is the focal length of microscope lens.

Q.234. *What is the magnification of a simple microscope, when the final image is formed at infinity ?* **(1)**

Ans. M.P. $= \frac{D}{f}$, where D is distance of distinct vision and f the focal length of the lens.

Q.235. *In a simple microscope, is magnifying power always equal to magnification ? Give reasons.* **(2)**

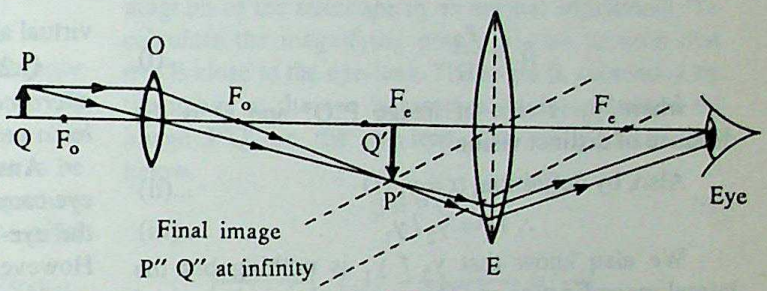
Ans. No, The magnifying power is $\frac{250 \text{ mm}}{|u|}$ and magnification is $\frac{|v|}{|u|}$. Only if the image formed by microscope is at distance of distinct vision, the magnification and magnifying power are numerically equal.

Q.236. *Magnifying power of a simple microscope is inversely proportional to the focal length of the lens. What stops us from using a convex lens of smaller and smaller focal length and achieving greater and greater magnifying power?* **(2)**

Ans. In a simple microscope magnifying power is inversely proportional to focal length f of lens. If f is small, magnifying power is large. However, for small value of f the radii of curvature of the lens surface must be small. This means lens surfaces should be highly curved. As the curvature of lens surfaces increases, the image formed is distorted.

Q.237. *Draw a ray diagram showing the formation of the final image at infinity by a compound microscope.* **(2)**

Ans. Fig. below shows the ray diagram of a compound microscope, so that final image is at infinity. This will happen when the image P′Q′ formed by objective is situated at the focus of the eye-lens. In this case the magnifying power is smaller than when image is formed at distance of distinct vision.



Q.238. *Explain with the help of a clear ray diagram the construction and working of a compound microscope. Obtain an expression for its magnifying power.* **(5)**

Ans. A compound microscope makes use of two convex lenses. Magnification is much more than in case of a simple microscope. The lens O, known as objective, is so placed that the object to be magnified is placed just beyond the focus. The objective forms a real, inverted and magnified image P′Q′. The image P′Q′ lies within the focus of the eye lens E. The eye-lens acting as a simple microscope forms a magnified, virtual and erect image P"Q". Fig. below shows the microscope, so set that final image is formed at the distance of distinct vision. In Fig. PQ is the real object, situated just beyond the focus F of the object lens. The image P′Q′ lies within the focus Fe of the eye-lens. The final image P"Q" is formed at the distance of distinct vision. To locate P"Q" we have to imagine two rays 1 and 2 shown by dotted lines starting from point P′. The path of these rays is traced using the properties of the focus and optical centre. These two rays appear to meet at P". P" is the image of point P′ formed by eye-lens. The path of actual rays, shown by solid lines is such that they appear to come from point P". The magnifying power M, by definition is $M = \beta / \alpha$. From fig.

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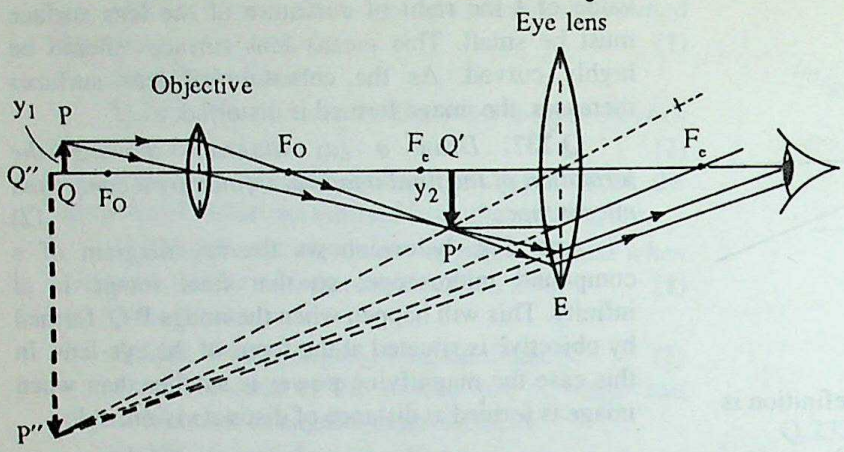


$$\beta = \frac{y_2}{D} \qquad ...(i)$$

where y_2 is size of image P"Q" and D is the distance of distinct vision.

Also, by definition, $\alpha = y_1 / D$ ...(ii)

$$\therefore M = y_2 / y_1 \qquad ...(iii)$$

We also know that y_2 / y_1 is nothing but the lateral magnification m. This means that as in case of simple microscope, for a compound microscope also magnifying power is equal to lateral magnification. If y_2' is size of image P'Q', we can rewrite eqn (iii) as

$$M = \frac{y_2}{y_1} = \frac{y_2}{y_2'} \times \frac{y_2'}{y_1} = m_e \times m_o \qquad ...(iv)$$

where m_0 and m_e denote the lateral magnification of object and eye-piece respectively. Since eye lens acts as a simple microscope, we can write m_e, as

$$m_e = (D/f_e) + 1$$

For objective lens O, from lens relation

$$m_o = \frac{y_2'}{y_1} = -v_1/u_1 \qquad ...(v)$$

where v_1 and u_1 denote object, PQ, and image P' Q' position respectively with respect to lens O. Also

$$\frac{1}{v_1} - \frac{1}{u_1} = \frac{1}{f_o} \text{ or } 1 - \frac{v_1}{u_1} = \frac{v_1}{f_o} \text{ or } -\frac{v_1}{u_1} = \frac{v_1}{f_o} - 1$$

$$m_o = (v_1/f_o) - 1 \qquad ...(vi)$$

Combining eqn (iv) (v), and (vi) we can rewrite,

$$\therefore \quad M = \left((D/f_e) + 1\right)\left((v_1/f_o) - 1\right) \qquad ...(vii)$$

It is obvious from eqn (vii) that for M to be large, both f_0 and f_e must be small.

Q.239. *What is the length of a compound microscope, when the final image is formed at infinity ?* (1)

Ans. The length of compound microscope is more than $f_0 + f_e$, where f_0 and f_e denote the focal length of O - and the E lens respectively.

Q.240. *What is the nature of final image formed by a compound microscope ?* (1)

Ans. The final image formed in a compound microscope is inverted with respect to the object. It is also virtual and magnified.

Q.241. *When viewing through a compound microscope, the eye is not positioned on the eye lens but a small distance away from it. Why ?* (2)

Ans. When eye is placed close to the E-lens the eye cannot collect all the rays undergoing reflection at the eye-lens. The field of view, therefore, is narrow However, if eye is placed at some distance from the eye-lens, the eye will collect more of the refracted rays.

Q.242. *In a compound microscope what is the relation between the magnifying power of the microscope and the magnification of objective and eye lens ?* (1)

Ans. $M.P = m_0 \times m_e$

where m_0 and m_e denote magnification of objective and eye lens respectively.

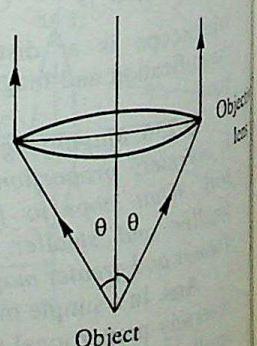
Q.243. *Define (i) magnifying power (ii) resolving power and (iii) numerical aperture. What is the relation between them ?* (3)

Ans. (i) The magnifying power (M.P) is the ratio of the angular size of the image and the object.

(ii) The resolving power (R.P) of a microscope is a measure of how close the objects can be and they are still seen separate in the field of view . The smallest distance x between two objects that are seen as separate with the help of a microscope is

$$x = \frac{1.22\lambda}{2\mu \sin\theta}$$

where λ is wavelength of light used, μ is refractive index of object space and θ



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is the semi-vertex angle of the cone formed by the extreme rays entering the objective of microscope as shown in fig.

(iii) The numerical aperture (N.A) is $\mu \sin\theta$, where μ is refractive index of object space and θ is the semi-vertex angle of the cone formed by the extreme rays entering the objective of microscope, as shown in fig.

Maximum magnifying power of a microscope

$$= \frac{\text{Resolving power of the eye}}{\text{Resolving power of microscope}}$$

Also, Resolving power of microscope

$$= \frac{0.61\,\lambda}{\text{Numerical aperture}}$$

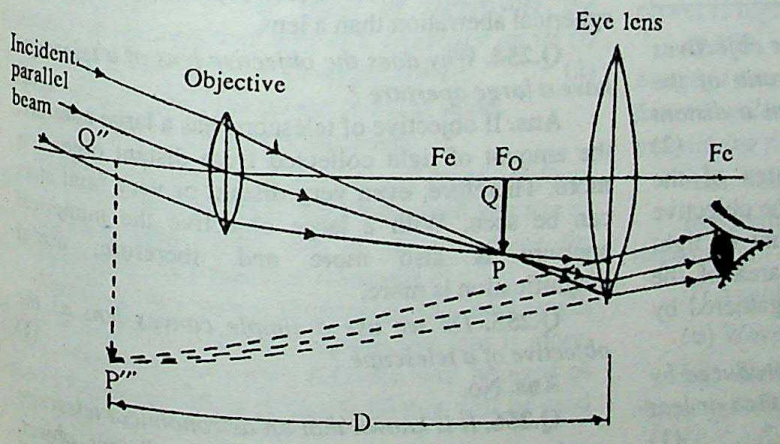
Q.244. *Why an oil immersion or ultra microscope reveals greater detail of the object magnified ?* **(2)**

Ans. In an oil immersion microscope the refractive index of medium (μ) in which object to be magnified is placed is higher. The numerical aperture (N.A) is more, therefore, maximum useful magnification is more.

In an ultra microscope, the object is illuminated with ultra-violet rays. λ for ultra-violet rays is less than λ for visible light. Therefore, resolving power (R.P.) of microscope is more.

Q.245. *Draw a ray diagram showing the formation of the final image at the distance of distinct vision for an astronomical telescope.* **(2)**

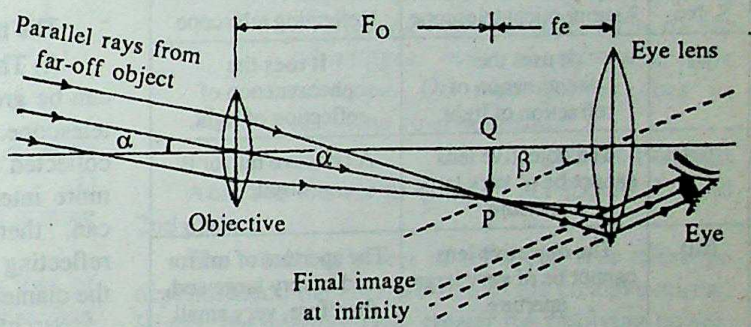
Ans.



Q.246. *With the help of a clear ray diagram explain the construction and working of an astronomical telescope. Obtain its magnifying power. Why reflecting type telescopes are better than refracting type telescopes ?* **(5)**

Ans. An astronomical telescope consists of two converging lenses. The objective lens O has a long focal length. The eye-lens E has short focal length. Since the object to be viewed is situated very far off, we consider a parallel beam incident on the objective. The eye-lens E is so arranged in the normal adjustment that P′Q′ is at the focus of eye-lens E and final image is formed at infinity. Fig. below is the ray diagram of the telescope in its normal adjustment. To calculate the magnifying power M, we assume that eye is close to the eye-lens. The angle β, subtended by the image at the eye is same as angle subtended by image P′Q′ on the eye-lens. Obviously, from fig. below.

$$\beta = P'Q'/f_e \qquad ...(i)$$



Since the length of the telescope is very small as compared to the object distance, the angle subtended , at the eye by the object is equal to the angle subtended by the object at the objective O. Clearly, from fig

$$\alpha = P'Q'/f_o \qquad ...(ii)$$

The magnifying power, M, by definition is

$$M = \beta/\alpha = f_o/f_e \qquad ...(iii)$$

Obviously, for *higher magnifying power the focal length of objective should be large and that of the eye-lens small.* It is also obvious from fig. that the length of telescope, in normal adjustment, is equal to $f_o + f_e$.

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Q.247. *What is the length of a telescope in normal adjustment ?* (1)

Ans. $f_o + f_e$, where f_o and f_e denote the focal length of the O and E lens respectively.

Q.248. *What is the nature of final image obtained in an astronomical telescope ?* (1)

Ans. The final image formed is virtual, inverted and magnified.

Q.249. *What is the difference between astronomical and terrestrial telescope ?* (2)

Ans. An astronomical telescope consisits of two convex lenses. The terrestrial telescope has three convex lenses. In an astronomical telescope the final image formed is inverted. In terrestrial telescope the final image formed is erect. The length of a terrestrial telescope is more than that of an astronomical telescope.

Q.250. *What is the difference between astronomical and reflecting telescope ?* (2)

Ans.

S. No.	Astronomical telescope	Reflecting telescope
(i)	It uses the phenomenon of refraction of light.	It uses the phenomenon of reflection of light,
(ii)	The objective lens cannot be of very large aperture.	A concave mirror is used,
(iii)	The objective lens cannot be of very large aperture.	The aperture of mirror used is very large and, therefore, very small and very distant objects can be photographed.

Q.251. *The ratio of the apertures of the objectives of two telescope is 1 : 4. What is the ratio of the amount of light gathered by the two from a distant star?* (2)

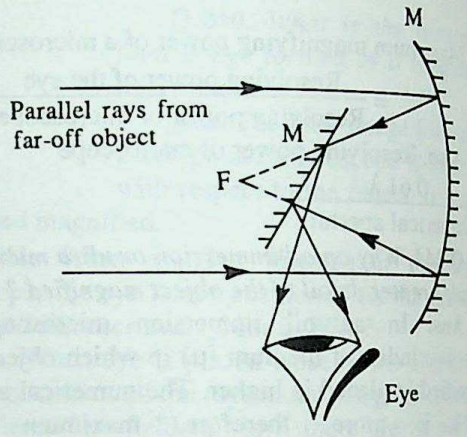
Ans. Since the ratio of the apertures of the objectives is 1 :4, the ratio of the area of the objective of the two telescopes is 1:16. The amount of light gathered is directly proportional to the area of the aperture, therefore, the ratio of the light gathered by the two telescopes is 1:16.

Q.252. *Is the angular magnification produced by a terrestrial telescope is equal to, greater than or less than that due to an astronomical telescope ?* (1)

Ans. Same as that of astronomical telescope.

Q.253. *Explain the working of a reflecting telescope with the help of a clear ray diagram.* (3)

Ans. The reflecting telescope makes use of a concave mirror to form the image of the distant object. Fig. below shows a *Newtonian* reflecting telescope. The mirror M, is used as the objective and forms an image of the distant object at its (mirror M) focus F. The image formed is viewed by eye using a plane mirror M as shown in fig.



The main advantages of a reflecting telescope are:

(i) The aperture of the mirror used as an objective can be greater than that of a lens used in a refracting telescope. This results in large amount of rays being collected from the distant object, so that final image is more intense. Even very distant or less intense stars can, therefore, be viewed. The world's largest reflecting telescope is in Russia on *Mt. Pastukhov* and the diameter of its mirror is 6 m.

(ii) There is no chromatic aberration.

(iii) A paraboloidal mirror objective produces less spherical aberration than a lens.

Q.254. *Why does the objective lens of a telescope have a large aperture ?* (2)

Ans. If objective of telescope has a large aperture, the amount of light collected from distant objects is more. Therefore, even very distant or very faint stars can be seen. With a large objective the numerical aperture is also more and, therefore, useful magnification is more.

Q.255. *Do we use a simple convex lens as the objective of a telescope ?* (1)

Ans. No.

Q.256. *It is known that an astronomical telescope produces an inverted image of the distant object. Which type of telescope do we use here on the earth which does not have this disadvantage ?* (1)

Ans. Terrestrial telescope

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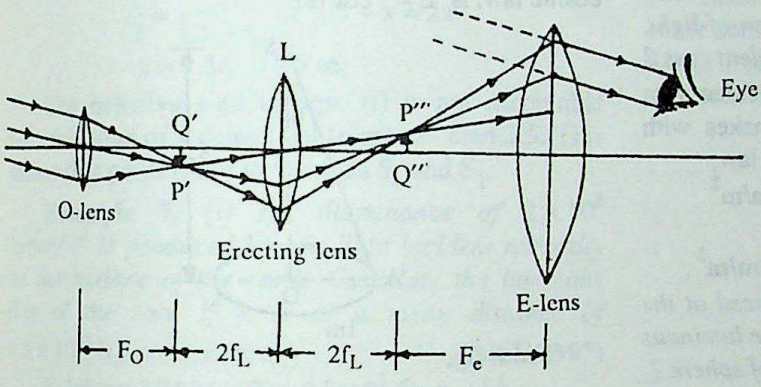
Q.257. *Explain the essential details and give a ray diagram for the terrestrial telescope.* **(3)**

Ans. In a terrestrial telescope a lens L is introduced between objective and eye-lens. The lens L is at a distance $2F_L$ from image P′Q′ formed by the O-lens. P′Q′ acts as object for lens L which forms its image P″Q″. P″Q″ has same size as P′Q′ but is inverted with respect to P′Q′. P″Q″ acts as object for E-lens. The final image is, therefore, erect. Fig. gives the ray diagram showing formation of image.



Q.258. *What can be regarded as a main drawback of a terrestrial telescope ?* **(1)**

Ans. (i) The length of terrestrial telescope is more than that of astronomical telescope.

(ii) Due to use of erecting lens there is loss of intensity. The final image formed is less intense than in an astronomical telescope.

Q.259. *What is the effect of increasing the diameter of the objective lens of a telescope on its (i) magnifying power and (ii) resolving power.* **(2)**

Ans. (i) Magnifying power remains same.

(ii) The resolving power increases.

Q.260. *You are given two convex lenses of focal length 80 mm and 800 mm. Which one will you use as an objective and which one as an eye piece for constructing an astronomical telescope ?* **(1)**

Ans. In an astronomical telescope the focal length of eye-lens is small and that of objective lens is more. Hence, lens of focal length 800 mm will be used as objective and lens of focal length 80 mm will be used as eye-lens.

Q.261. *Draw a labelled diagram to show image of an object in a compound microscope.*

(CBSE 1999) (2)

Ans. See answer to question no. 237.

Q.262. *Draw a labelled diagram to show the image formation in an astronomical telescope for normal adjustment position. Write down the expression for its magnifying power.*

(CBSE 1999) (2)

Ans. See answer to question no. 246.

Q.263. *How will magnifying power of a refracting type astronomical telescope be affected on increasing for its eye-piece*

(i) the focal length and (ii) the aperture? Justify your answer. **(CBSE 1997) (3)**

Ans. (i) We know that $m = \frac{f_0}{f_e}$, therefore, when f_e is increased, m is decreased.

(ii) On increasing the aperture of the eye-piece, magnifying power does not change.

Q.264. *Draw a labelled ray diagram to show the image formation in a reflecting type telescope. Write its two advantages over a refracting type telescope. On what factors does its resolving power depends?*

(CBSE 1998) (3)

Ans. See answer to question no. 253 for 1st and 2nd parts.

The resolving power of reflecting type telescope depends upon the aperture size of the concave mirror. Higher the aperture size, greater the resolving power. Also, for shorter wavelength of light the resolving power is higher.

Q.265. *Draw a ray diagram to show how an image is formed by a compound microscope. On what factors will depend (i) its resolving power (ii) its magnifying power?* **(CBSE 1998) (3)**

Ans. See answer to question 238 for 1st part.

Resolving power of a compound microscope depends on:

(i) Angular aperture of the objective.

(ii) Wavelength of light used.

(iii) Refractive index of the medium between object and objective lens.

Magnifying power of a compound microscope depends upon :

(i) The focal length of the objective.

(ii) The focal length of the eye-piece.

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Q.266. *Draw a labelled ray diagram showing the formation of image using a Newtonian type reflecting telescope.*

(CBSE 2000) (2)

Ans. See answer to question 253.

Q.267. *Draw a labelled ray diagram showing the formation of image of a distant object using an astronomical telescope in the normal adjustment position.*

(CBSE 2000) (2)

Ans. See answer to question 246.

SOLVED NUMERICAL PROBLEMS ON UNIT - IX

Example 1. *A source of 100 cd is placed at a distance of 2.5 m from a wall. What is the illuminance on wall, if (i) wall is normal to the direction of light, (ii) the wall makes an angle of 60° with incident rays ?*

Solution. (i) Since wall is normal to incident ray, the angle θ which the normal to wall makes with incident ray is zero. From Lambert's cosine law,

$E = I \cos\theta / r^2 = 100 \cos 0°/2.5^2 = \mathbf{16\ lm/m^2}$

(ii) Here $\theta = 60°$, therefore,

$E = 100 \cos 60° / (2.5)^2 = 16 \times 0.5 = \mathbf{8\ lm/m^2}$.

Example 2. *A source of 400 cd is placed at the centre of a sphere of radius 5 m. What is the luminous flux through an area 0.5 m^2 on the surface of sphere ?*

Solution. The luminous flux ϕ from the source is

$\phi = 4\pi I = 4\pi \times 400$ lumen.

The source being at the centre of a sphere of radius r = 5 m; the total flux crossing the surface area of sphere is ϕ. The illuminance E,

$$E = \frac{\Phi}{4\pi r^2} = \frac{4\pi \times 400}{4\pi \times (5)^2} = 16\ lm/m^2$$

Let Φ_1 be the luminous flux through an area dA. Then $\Phi_1 = E \times dA$

or $\Phi_1 = 16 \times (0.5) = \mathbf{8\ l\ m}$

Example 3. *A 200 W lamp produces a luminous intensity of 286 cd. What is the efficiency of lamp ?*

Solution : Efficiency

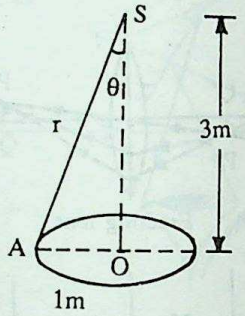
$$\eta = \frac{\text{Luminous flux in visible region}}{\text{Input electric power}} = \Phi/W$$

The luminous flux, $\Phi = 4\pi I$, where I is intensity of source. Therefore,

$$\eta = \frac{4\pi I}{W} = \frac{4 \times 3.142 \times 286}{200}\ lm/W = \mathbf{18\ lm/W}$$

Example 4. *A circular table has a diameter of 2 m. A point source of 200 cd is suspended 3 m vertically above the centre of the table. What is illumination at the edge of the table ?*

Solution : Fig. below shows circular table of radius OA = 1m. The source S is at a distance OS = 3m above the centre. The illumination E at a point A on the edge of the table, according to Lambert's cosine law, is $E = I \cos\theta / r^2$



From fig,

$r^2 = OA^2 + OS^2 = (1)^2 + (3)^2 = 10\ m^2$

and $\cos\theta = OS/AS = 3/\sqrt{10} = 3/3.162 = 0.948$

$$\therefore E = \frac{200 \times 0.948}{10} = \mathbf{18.96\ lm/m^2}.$$

Example 5. *A lamp placed 60 cm from a screen on one side produces the same illumination as a standard 60 cd lamp placed 120 cm away on the other side of the screen. What is the luminous intensity of the first lamp ?*

Solution : Let I be the luminous intensity of the first lamp . Then,

$$\frac{I}{60} = \left(\frac{60\ cm}{120\ cm}\right)^2$$

or $$I = 60 \times \left(\frac{1}{2}\right)^2 = \mathbf{15\ cd.}$$

Example 6. *Two lamps of 5 and 20 cd are placed 1.5 m apart. At what point in between them the illumination due to either lamp is same.*

Solution : Fig. below shows two lamps S_1 and S_2. Let the illumination due to either source at point P be same. Point P is at a distance x from S_1. Therefore,

$$\frac{I_1}{x^2} = \frac{I_2}{(1.5-x)^2} \Rightarrow \frac{I_1}{I_2} = \left(\frac{x}{1.5-x}\right)^2$$

or $$\frac{5}{20} = \left(\frac{x}{1.5-x}\right)^2 \text{ or } \pm\frac{1}{2} = \left(\frac{x}{1.5-x}\right) \quad ...(1)$$

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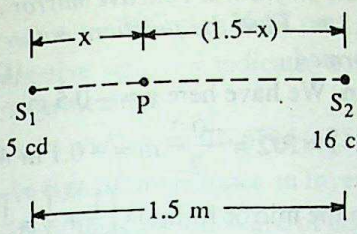


Taking the plus sign in eqn (i)

$$\frac{1}{2}=\frac{x}{1.5-x} \text{ or } 1.5-x=2x$$

$\therefore$ $x = 1.5/3 = \mathbf{0.5\ m}$.

The negative sign in eqn. (i) is not acceptable because value of x comes out to greater than 1.5. This means that point is not in between S_1 and S_2.

Example 7. *(i) An illuminance of 2×10^5 lumen/m^2 is produced by sun light incident normally on the surface of the earth. Calculate the luminous flux of the sun, if it is at a mean distance of 1.5×10^{11} m from the earth.* **(CBSE 1997)**

Solution: We have $E = 2\times10^5$ lumen/m^2

$r = 1.5\times10^{11}$ m

$$E=\frac{\phi}{4\pi r^2} \Rightarrow \phi = E\,.\,4\pi r^2.$$

$$=2\times10^5\times4\times3.14\times(1.5\times10^{11})^2$$

$$=\mathbf{5.6\times10^{28}\ lumen.}$$

Example 8. *A 60 W lamp is rated at 0.8 watt/candela.*

Calculate : (i) Luminous intensity of the lamp.

(ii) Luminous flux of the lamp

(iii) Illuminance at a distance of 2 m from the lamp. **(CBSE 1999)**

Solution: Give, power of the lemp = 60 w

Rating = 0.8 w/cd

(i) $I=\frac{\text{Power}}{\text{Rating}}=\frac{60}{0.8}=\frac{600}{8}=\mathbf{75\ cd}$

(ii) $\phi = 4\pi I = 4\times\frac{22}{7}\times75 = \mathbf{942.8\ lumen.}$

(iii) $E=\frac{I}{r^2}=\frac{75}{4}=\mathbf{18.35\ lumen.}$

Example 9. *An object, 0.04 m high, is placed at a distance of 0.8 m from a concave mirror of focal length 0.4 m. Find the position, nature and size of the image formed ?* **(C.B.S.E 1994 Comptt.)**

Solution : We have here u = – 0.8 m, f = – 0.4 m.

Hence, using the formula, $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$,

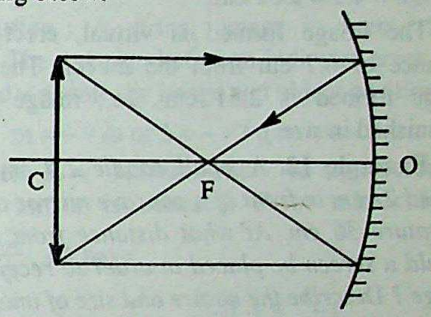
we get $\frac{1}{v}=\frac{1}{f}-\frac{1}{u}=-\frac{1}{0.4}-\frac{1}{(-0.8)}$

$$=\frac{-10}{4}+\frac{10}{8}=-\frac{10}{8}$$

$$v = -8/10\ \text{m} = \mathbf{-0.8\ m}$$

The image formed is, thus, a real, inverted image formed at the same position as the object. The magnification, thus, has a unit magnitude (|m| = v/u).

Thus, the image formed is a real, inverted image, of the same size as the object, formed at a distance of 0.8 m from the mirror. The relevant ray diagram is shown in fig below.



Example 10. *An object is kept in front of a concave mirror of focal length 15 cm. The image formed is three times the size of the object. Calculate two possible distance of the object from the mirror.* **(CBSE 1998)**

Solution: We know that $\frac{1}{f}=\frac{1}{u}\pm\frac{1}{v}$

By the given conditions

$$\frac{1}{15}=\frac{1}{u}\pm\frac{1}{3u} \Rightarrow \frac{3u}{3\pm1}=15$$

$$\Rightarrow u=\frac{15}{3}\times4=\mathbf{-20\ cm.}$$

($\because$ u is negative for concave mirror)

or $u=\frac{15}{3}\times2=\mathbf{-10\ cm.}$

Example 11. *A 4.5 cm needle is placed 12 cm away from a convex mirror of focal length 15 cm. Give the location of the image and magnification.*

Solution. Given

u = –12 cm [–ve sign because object is real]

f = +15 cm [+ ve sign because mirror is convex],

v = ?

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From the mirror formula $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$, we get

$$\frac{1}{v}+\frac{1}{(-12)}=\frac{1}{(+15)}$$

$$\frac{1}{v}=\frac{1}{12}+\frac{1}{15}=\frac{5+4}{60}=\frac{9}{60}$$

$\therefore$ v = 60/9 $\approx$ **6.7 cm.**

Since v is positive, the image formed is virtual. The magnification, m, is

$$m = -v/u = -6.7/(-12) = +0.558$$

The positive sign of magnification indicates an erect image.

Also, length of image = |m| × length of object = 0.558×4.5 = **2.51 cm.**

The image formed is virtual, erect and at a distance of 6.7 cm from the mirror. The length of image formed is 2.51 cm (i.e., image formed is diminished in size.)

Example 12. *A small candle 2.5 cm in size is placed 27 cm in front of a concave mirror of radius of curvature 36 cm. At what distance from the mirror should a screen be placed in order to receive a sharp image ? Describe the nature and size of image.*

Solution : Given u = – 27 cm [–ve sign because object is real]

R = – 36 cm [–ve sign because it is a concave mirror], v = ?

From the mirror formula, $\frac{1}{v}+\frac{1}{u}=\frac{2}{R}$, we get

$$\frac{1}{v}+\frac{1}{(-27)}=\frac{2}{(-36)}$$

or $$\frac{1}{v}=-\frac{1}{18}+\frac{1}{27}=\frac{-3+2}{54}=-\frac{1}{54}$$

$\therefore$ v = **– 54 cm**

The negative sign of v indicates a real image. The screen should be placed at a distance of 54 cm from the mirror.

Let m be the lateral magnification. Then

$$m = -v/u = -(-54)/(-27) = -2$$

The negative sign of m indicates an inverted image. Also

$$\frac{\text{Length of image}}{\text{Length of object}} = -2,$$

$\therefore$ Length of image = -2×2.5 = **– 5 cm.**

The image formed is real, inverted, at a distance of 54 cm from the mirror. The length of image is 5 cm.

Example 13. *An object 0.05 m high is placed at a distance of 0.5 m from a concave mirror of radius of curvature 0.2 m. Find the position, nature and size of the image formed* **(CBSE 1994)**

Solution. We have here u = – 0.5 m,

$$f = R/2 = \frac{-0.2}{2}\ m = -0.1\ m$$

$\therefore$ From the mirror formula $\left(\frac{1}{u}+\frac{1}{v}=\frac{1}{f}\right)$ we get

$$\frac{1}{v}=\frac{1}{f}-\frac{1}{u}=-\frac{1}{0.1}-\frac{1}{-0.5}=-10+2=-8$$

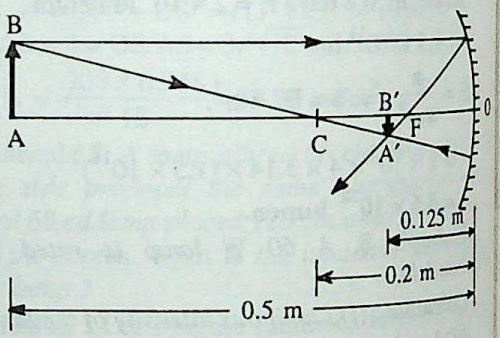
$\therefore$ $v=-\frac{1}{8}\ m = -0.125$ **m.**

The image formed is, thus, a real inverted image. The magnification, m, is given by

$$m=-\frac{v}{u}=\frac{-(-0.125)}{-0.5}=-0.25$$

The image formed is, thus, at a distance of 0.125 m from the mirror, on the same side as the object. It is real and inverted and has a size of 0.0125 m.

The relevant ray diagram is shown in fig. below.



Example 14. *A square wire of size 3.0 cm is placed 25 cm away from a concave mirror of focal length 10 cm. What is the area enclosed by the image of wire ? (The centre of wire is on the axis of the mirror with its two sides normal to the axis).*

Solution : Given, u = –25 cm [–ve sign because object is real]

f = –10 cm [–ve sign because mirror is concave]

v = ?

From the mirror formula $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$, we get

$$\frac{1}{v}+\frac{1}{(-25)}=\frac{1}{(-10)}$$

or $$\frac{1}{v}=\frac{-1}{10}+\frac{1}{25}$$

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$$= \frac{-5+2}{50} = \frac{-3}{50}$$

$\therefore$ v = – 50/3 = **– 16.67 cm**

The negative sign of v indicates a real image. Let m be the magnification.

Then, m = – v/u = – (–16.67) / (–25) = –0.667

The –ve sign of m indicates an inverted image.

The size of image = |m| × size of object

= 0.667 × 3 = 2 cm.

The area enclosed by image = 2 × 2 = **4 cm²**.

Example 15. *An object is kept in front of a concave mirror of focal length 20 cm. The image formed is three times the size of the object. Calculate two possible distances of the object from the mirror.*

Solution : The magnified image can be (i) a virtual image, (ii) a real image. Corresponding to these two cases, we have

(i) $\frac{v}{u} = -3$ or $v = -3u$

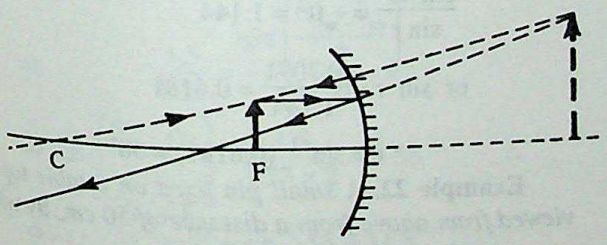
$\therefore$ Using the mirror formula

$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$, we get

$$-\frac{1}{3u} + \frac{1}{u} = \frac{1}{f} \text{ or } \frac{-1+3}{3u} = \frac{1}{f}$$

or $u = \frac{2f}{3} = \frac{2(-20)}{3}$ cm = **13.3 cm**

The relevant ray diagram is shown in adjoining fig.

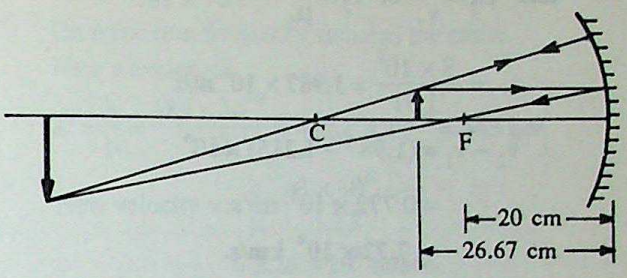


(ii) $\frac{v}{u} = +3$ or $v = 3u$

$$\therefore \frac{1}{3u} + \frac{1}{u} = \frac{1}{f} \text{ or } \frac{1+3}{3u} = \frac{1}{f}$$

or $u = \frac{4}{3}$ f = $\frac{4}{3} \times (-20\_$ cm = **– 26.67 cm.**

The relevant ray diagram for this case is shown in adjoining fig.



Example 16. *A dentist's concave mirror has a radius of curvature of 30 mm. How far must it be placed from a small cavity in order to give a virtual image 5 times larger ?*

Solution : A virtual image is erect. Hence, m = +5. The +ve sign before m indicates erect image. Let u and v denote the image and object position.

m = – v /u or 5 = – v / u or v = – 5 u

Given, R = –30 mm. The – ve sign before R is because mirror is concave. From mirror formula $\frac{1}{v} + \frac{1}{u} = \frac{2}{R}$, we have

$$\frac{1}{(-5u)} + \frac{1}{u} = \frac{2}{(-30)} \text{ or } \frac{-1+5}{5u} = \frac{-1}{15}$$

$\therefore u = -\frac{4 \times 15}{5}$ mm or **u = – 12 mm**

The negative sign of u indicates a real image. The dentist's mirror should be at a distance of 12 mm or 1.2 cm from the cavity.

Example 17. *Light of wavelength 6000 Å in air enters a medium of refractive index 1.5. What will be its frequency in the medium ?* **(C.B.S.E 1994)**

Solution : We know that frequency does not change as light goes from one medium to another. Hence, frequency in medium = frequency in air = c/λ

$$= \frac{3 \times 10^8}{6000 \times 10^{-10}} \text{ Hz} = 5 \times 10^{14} \text{ Hz.}$$

Example 18. *The refractive index of diamond is 2.47; that of window glass is 1.51. How much faster does light travel in window glass than in diamond ?*

Solution : Let μ_1 and μ_2 be the refractive index and v_1 and v_2 be the velocity of light in diamond and window glass. Then, by definition

$$\mu_1 = \frac{c}{v_1} \text{ or } v_1 = \frac{c}{\mu_1} = \frac{3 \times 10^8}{2.47}$$

$= 1.215 \times 10^8$ m/s.

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and $\mu_2 = \frac{c}{v_2}$ or $v_2 = \frac{c}{\mu_2}$

$$= \frac{3 \times 10^8}{1.51} = \mathbf{1.987 \times 10^8\ m/s.}$$

$$\therefore\ v_2 - v_1 = (1.987 - 1.215) \times 10^8$$

$$= 0.772 \times 10^8\ \text{m/s.}$$

$$= \mathbf{7.72 \times 10^4\ km/s.}$$

Thus, light travels 7.72×10^4 km/s faster in window glass than in diamond.

Example 19. *For the same angle of incidence, the angles of refraction in three different media A, B and C are 15°, 25° and 35° respectively. In which medium will the velocity of light be minimum ?*

Solution : The velocity of light in a medium of refractive index μ is given by $c' = c/\mu$, when c = velocity of light in vacuum.

Now, $\mu = \frac{\sin i}{\sin r}$. Hence, for the same angle of incidence, μ will be maximum when r is a minimum.

Thus, μ is maximum for medium A. Hence, velocity of light will be minimum in medium A.

Example 20. *A ray of light travels from water to glass. What will be the angle of refraction in glass, if the angle of incidence in water is 20° ? The refractive index of water is 1.33 and that of glass is 1.5.*

Solution : Let ${}_w\mu^g$ be the refractive index of glass with respect to water, then ${}_w\mu^g = \mu^g/\mu^w$, where μ^w and μ^g are the absolute refractive indices of water and glass. We are given

$$\mu^w = 1.33,\ \mu^g = 1.5$$

$$\therefore\ {}_w\mu^g = 1.5/1.33 = 1.125$$

Let i and r be angle of incidence and angle of refraction when rays pass from water to glass.

Then, ${}_w\mu^g = \frac{\sin i}{\sin r}$. Given, i = 20°

$$\sin r = \sin 20°/1.125 = 0.0300$$

$$r = \sin^{-1} 0.3040 = \mathbf{17°42'}.$$

Example 21. *Fig. (a) and (b) below show refraction of an incident ray in air at 60° with the normal to a glass-air and water-air interface respectively. Predict the angle of refraction of an incident ray in water at 45° with the normal to water-glass interface.*

Solution : Let ${}_a\mu^g$ be refractive index of glass with respect to air.

$${}_a\mu^g = \frac{\sin 60°}{\sin 35°} = \frac{0.866}{0.5736} = 1.51$$

Similarly, let ${}_a\mu^w$ be refractive index of water with respect to air. From fig. (b) using Snell's law

$${}_a\mu^w = \frac{\sin 60°}{\sin 41°} = \frac{0.866}{0.6561} = 1.32$$

Let ${}_w\mu^g$ be refractive index of glass with respect to water. Then

$${}_w\mu^g = \frac{{}_a\mu^g}{{}_a\mu^w} = \frac{1.51}{1.32} = 1.144$$

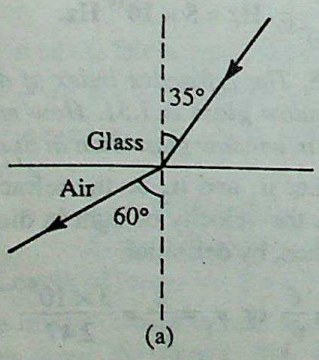
Let *r* be angle of refraction in fig. (c) From Snell's law

$$\frac{\sin 45°}{\sin r} = {}_w\mu^g = 1.144$$

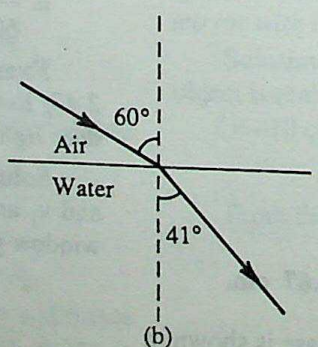
$$\text{or } \sin r = \frac{0.7071}{1.144} = 0.6181$$

$$\therefore\ r = \sin^{-1}(0.6181) = \mathbf{38°}.$$

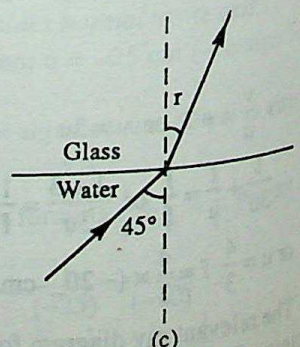
Example 22. *A small pin fixed on a table top is viewed from above from a distance of 50 cm. By what*



(a)



(b)



(c)

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distance would the pin appear to be raised, if it is viewed from the same point through a 15 cm thick glass slab held parallel to the table?

Refractive index of glass is 1.5. Does the answer depend on the location of glass slab ?

Solution : Let μ and t denote the refractive index and thickness of glass slab. The pin appears raised by

$$t\left(1-\frac{1}{\mu}\right)=15\left(1-\frac{1}{1.5}\right)=\frac{15.\times 0.5}{1.5}=\mathbf{5\ cm.}$$

The answer does not depend on the location of the glass slab.

Example 23. *At what angle of incidence should a light beam strike a glass slab of refractive index $\sqrt{3}$ such that the refracted and the reflected rays are perpendicular to each other?* **(CBSE 1997 Comptt.)**

Solution: When refracted and reflectged rays are perpendicular to each other then

$$\mu=\tan i_p \Rightarrow \sqrt{3}=\tan i_p \Rightarrow i_p=\mathbf{60^\circ}$$

Example 24. *A glass prism of refracting angle 60° and refractive index 1.5 is completely immersed in water of refractive index of 1.33. Calculate the angle of minimum deviation of the prism in this situation* $(\sin^{-1} 0.56 = 34.3^\circ)$ **(CBSE 1997 Comptt.)**

Solution: We have

$A = 60^\circ, \mu_g = 1.5, \mu_w = 1.33$

$$\frac{\mu_g}{\mu_w}=\frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\frac{A}{2}}$$

$$\Rightarrow \quad \frac{1.5}{1.33}=\frac{\sin\left(\frac{60+\delta_m}{2}\right)}{\sin 30^\circ}$$

$$\Rightarrow \sin\left(\frac{60+\delta_m}{2}\right)=\frac{1.5}{1.33\times 2}=0.56$$

$$\Rightarrow \quad \frac{60+\delta_m}{2}=\sin^{-1}56=34.3^\circ$$

$$\Rightarrow \quad \delta_m=34.3\times 2-60^\circ=\mathbf{8.6^\circ}.$$

Example 25. *Monochromatic light of wavelength 589 nm is incident from air on a water surface. What are the wavelength, frequency and speed of a (i) reflected (ii) refracted light?*

(μ for water = 1.33) **(CBSE 1997)**

Solution: (i) No change in case of reflection.

(ii) $\lambda = 589\ \text{nm} = 589\times 10^{-9}\ \text{m}$

$$\frac{c}{\lambda}=\frac{3\times 10^8}{589\times 10^{-9}}=\mathbf{5.09\times 10^{14}\ Hz.}$$

On refraction frequency remains the same.

New wavelength

$$\lambda'=\frac{\lambda}{\mu}=\frac{589\times 10^{-9}}{1.33}=442.8\times 10^{-9}=\mathbf{443\ nm}$$

New velocity $v=\frac{c}{\mu}=\frac{3\times 10^8}{1.33}$

$$=\mathbf{2.25\times 10^8\ m/sec.}$$

Example 26. *A ray of light passes through an equilateral glass prism such that the angle of incidence is equal to the angle of emergence. If the angle of emergence is 3/4 times the angle of the prism, calculate the refractive index of the glass prism.* **(CBSE 2000)**

Solution: Here, $\angle A = 60^\circ, i = i' = \frac{3\angle A}{4} = 45^\circ$

Now, $A + \delta_m = i + i'$

$\Rightarrow 60^\circ + \delta_m = 90^\circ \Rightarrow \delta_m = 30^\circ$

$$\mu=\frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\frac{A}{2}}=\frac{\sin\left(\frac{60+30}{2}\right)}{\sin 30^\circ}$$

$$=\frac{\sin 45^\circ}{\sin 30^\circ}=\frac{0.709}{0.5}=\mathbf{1.41.}$$

Example 27. *A tank is filled with water to a height 10 cm. The apparent depth of a needle lying at the bottom of the tank is measured by a microscope to be 7.5 cm. What is the refractive index of water. If water is replaced by a liquid of refractive index 1.60 up to the same height, by what distance would the microscope have to be moved to focus the needle again?*

Solution :

$$\mu=\frac{\text{Real depth}}{\text{Apparent depth}}=\frac{10}{7.5}=1.33$$

The apparent depth when water is replaced by liquid $=\frac{10}{\mu}=\frac{10}{1.6}=\mathbf{6.25\ cm.}$

The microscope, therefore, will have to be moved up by a distance of $(7.5 - 6.25) = \mathbf{1.25\ cm.}$

Example 28. *A pond of depth 40 cm is half filled with an oil of refractive index 1.4 and the other half is filled with water of refractive index 1.33. What is apperent depth of pond, when viewed normally?*

Solution : The apparent depth is the sum of the apparent depth of water and oil parts. Therefore,

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Apparent depth $= \frac{0.2}{1.4} + \frac{0.2}{1.33} \approx$ **0.293 m.**

Example 29. *Find the critical angle for water. Given* $_a\mu^w = 1.33$.

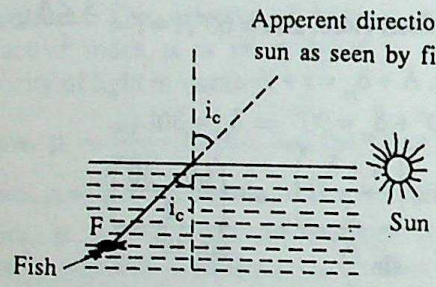
Solution : Let i_c be the critical angle, then

$$\sin i_c = 1/ {}_a\mu^w = 1/1.33 = 0.7519$$

$$\therefore i_c = \sin^{-1} 0.7518 = \mathbf{48.7°}.$$

Example 30. *What is the direction in which a fish under water sees the setting Sun ? Refractive index of water is 1.33.*

Solution : Fig. shows the setting sun S along the water surface. A ray of light starting from the sun after refraction, enters the eye of the fish. The apparent direction of the sun makes an angle i_c with the vertical. Applying Snell's law,



$$\sin \pi/2 = 1.33 \sin i_c$$

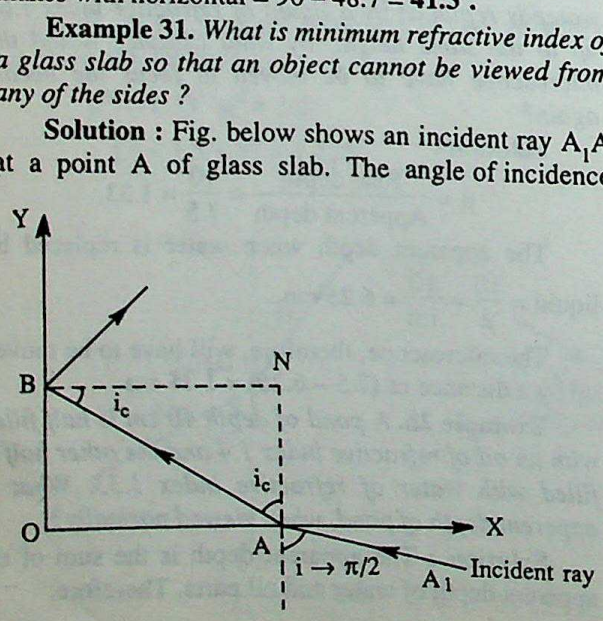
$$\Rightarrow \quad \sin i_c = 1/1.33 = 0.7518$$

$$\text{or } i_c = \sin^{-1}(0.7518) = \mathbf{48.7°}$$

The angle, the apparent direction of the sun makes with horizontal $= 90 - 48.7 = \mathbf{41.3°}$.

Example 31. *What is minimum refractive index of a glass slab so that an object cannot be viewed from any of the sides ?*

Solution : Fig. below shows an incident ray A_1A at a point A of glass slab. The angle of incidence $i = \pi/2$. The refracted ray at A is AB. The angle of refraction equals i_c. This ray is incident at point B on face OY of slab. In order that the object is not seen from side OY, the ray must undergo total internal reflection at point B. The angle of incidence at B is i_c. From right angled Δ OAB;



$$2 i_c = \frac{\pi}{2} \text{ or } i_c = \frac{\pi}{4}$$

The minimum refractive index (μ) of glass slab is

$$\mu = \frac{1}{\sin i_c} = \frac{1}{\sin 45°} = \sqrt{2}.$$

Example 32. *The refracting angle of a glass prism is 60°. The value of the angle of minimum deviation, for light passing through the prism is 40°. Calculate the value of the refractive index for the material of the prism. (sin 50° ≈ 0.766).*

(CBSE 1993 Comptt.)

Solution : We know that μ is given by

$$\mu = \frac{\left(\sin \frac{A + \delta_m}{2}\right)}{\sin A/2}$$

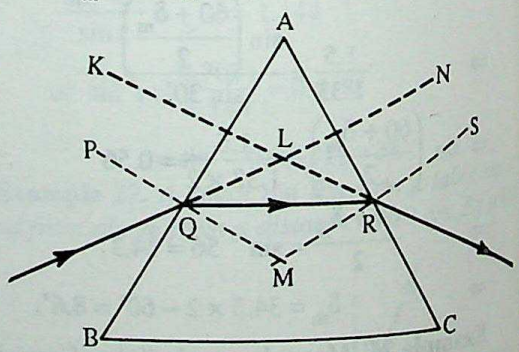
Here, $\delta_m = 40°$, $A = 60°$. Hence,

$$\mu = \frac{\sin (60 + 40°)/2}{\sin (60°/2)} = \frac{\sin 50°}{\sin 30°} = \frac{0.766}{0.5} = 1.532.$$

Example 33. *Calculate the refractive index of the material of an equilateral prism for which the angle of minimum deviation is 60°* **(CBSE 1994)**

Solution : For an equilateral prism, $\angle A = 60°$

Also, $\delta_m = 60°$ (given). Hence,



$$\mu = \frac{\sin (A + \delta_m)/2}{\sin A/2} = \frac{\sin 60°}{\sin 30°} = \frac{\sqrt{3}/2}{1/2} = \sqrt{3}$$

$\therefore$ The refractive index of the material of the given prism is $\sqrt{3}$, i.e., **1.732.**

Example 34. *A prism is set for minimum deviation position. The angle of incidence is 45° and refractive index of prism material is 1.6. What is the angle of minimum deviation?*

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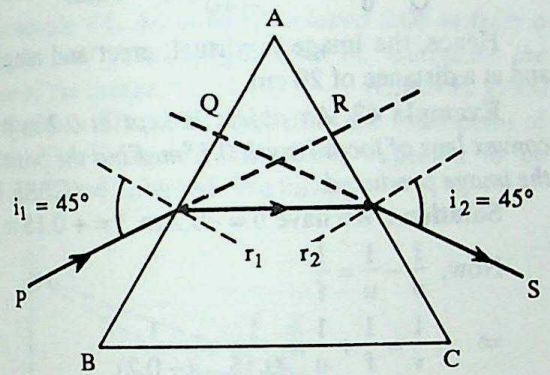
Solution : Let i_1 and r_1 be angle of incidence and refraction at point Q of prism. From Snell's law,

$$\sin i_1 = \mu \sin r_1$$

or $$\sin 45° = 1.6 \sin r_1$$

$$\therefore \quad \sin r_1 = \frac{0.707}{1.6} = 0.4419$$

$$\therefore \quad r_1 = \sin^{-1}(0.4419) = 26.23°$$



Since the ray is undergoing minimum deviation, the angle of incidence at R is also i_1 and $r_2 = r_1$. Also the angle of prism, A is

$$A = r_1 + r_2 = 2 \times 26.23 = 52.46°$$

For minimum deviated ray, the angle of emergence $i_2 = i_1 = 45°$.

The angle of minimum deviation δ_m is

$$\delta_m = i_1 + i_2 - A = 2 \times i_1 - A$$

$$= 2 \times 45 - 52.46 = 90 - 52.46 = \mathbf{37.54°}.$$

Example 35. *The radii of curvature of the two surfaces of a convex lens of focal length 0.27 m are 0.2 m and 0.6 m. What is the refractive index of the lens material?*

Solution. Given f = 0.27 m; $R_1 = +0.2$ m, $R_2 = -0.6$ m

From lens maker's formula

$$\frac{1}{0.27} = (\mu - 1)\left(\frac{1}{0.2} + \frac{1}{0.6}\right)$$

or $$\mu - 1 = \frac{0.6}{0.27 \times 4} = 0.55$$

$$\therefore \quad \mu = \mathbf{1.55}.$$

Example 36. *An equi-convex lens of focal length 0.3 m is made from glass of refractive index 1.50. What is the radius of curvature of each lens surface ?*

Solution : Let c be the magnitude of the radius of curvature of each lens surface. According to coordinate convention of signs, $R_1 = +c$; $R_2 = -c$.

Given, f = 0.3 m; $\mu = 1.50$. From lens maker's formula,

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\therefore \frac{1}{0.3} = (1.50 - 1)\left(\frac{1}{c} + \frac{1}{c}\right)$$

$$= 0.50 \times \frac{2}{c} \text{ or } c = \mathbf{0.3\ m}.$$

Example 37. *If the power of a lens is +5 diopter, what is its focal length?* **(CBSE 1994 Comptt.)**

Solution. We have $P = \frac{1}{f}$ or $f = \frac{1}{P}$

$$\therefore f = \frac{1}{5} \text{ metre} = \frac{1}{5} \times 100 \text{ cm} = \mathbf{20\ cm}.$$

Thus, the focal length of the lens is **(+) 20 cm.**

Example 38. *A convex lens of glass ($\mu = 1.5$) has a focal length of 200 mm.. The lens is immersed in water of refractive index 1.33. What is the change in power of the lens ?*

Solution : Let f_1 be the focal length of lens in air. Then, from lens maker's formula,

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

or $$\frac{1}{f} = (1.5 - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

or $$0.5\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \frac{1}{0.2}$$

or $$\frac{1}{R_1} - \frac{1}{R_2} = 10$$

The power P_1 of the lens in diopters is

$$P_1 = \frac{1}{f_1 \text{ (in metre)}} = \frac{1}{0.2} \text{ or } P_1 = +5D \quad ...(ii)$$

Let f_2 be the focal length of the lens, when it is immersed in water, then

$$\frac{1}{f_2} = \left(\frac{1.5}{1.33} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$= \frac{0.17}{1.33} \times 10 = \frac{1.7}{1.33} = +1.278$$

$$\therefore \quad f_2 = \frac{1}{1.278} = 0.78 \text{ m}$$

The power, P_2 of the lens when immersed in water is

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$$P_2 = \frac{1}{f_2} = +1.278\ D$$

The change in power of lens, ΔP, is

$$\Delta P = P_2 - P_1 = 1.278 - 5 = -3.722\ \mathbf{D}.$$

Example 39. *Glass has a refractive index of 1.5. A convex lens made of thin glass has a focal length of 20 cm in air. It is immersed in water whose refractive index is 4/3. Calculate the apparant changed focal length of the lens.* **(CBSE 1998)**

Solution: We have, $f = 20$ cm, $\mu = 1.5$

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ...(i)$$

$$\frac{1}{f'} = (\mu' - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ...(ii)$$

$$\left(\text{where } \mu' = \frac{\mu_g}{\mu_w}\right)$$

Dividing (i) by (ii)

$$\frac{f'}{f} = \frac{\mu - 1}{\mu' - 1} = \frac{1.5 - 1}{\frac{1.5}{4/3} - 1} = \frac{0.5 \times 4}{0.5} = 4$$

$$\Rightarrow f' = 4 \times f = 4 \times 20 = \mathbf{80\ cm}.$$

Example 40. *A converging lens has a focal length of 20 cm in air. It is made of a material of refractive index 1.6. If it is immersed in a liquid of refractive index 1.3, what will be its new focal length?* **(CBSE 1999)**

Solution: $$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ...(i)$$

$$\frac{1}{f'} = (\mu' - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ...(ii)$$

$$\left(\text{where } \mu' = \frac{\mu_g}{\mu_w}\right)$$

Dividing (i) by (ii)

$$\frac{f'}{f} = -\frac{\mu - 1}{\mu' - 1} = \frac{1.6 - 1}{\frac{1.6}{1.3} - 1} = \frac{0.6}{0.2307} = 2.6$$

$$\Rightarrow f' = f \times 2.6 = 20 \times 2.6 = \mathbf{52\ cm}.$$

Example 34. *A double convex lens made of glass of refractive index 1.5 has both radii of curvature of magnitude 20 cm. An object 2 cm high is placed at 10 cm from the lens. Find the position, size and nature of the image.* **(CBSE 1997 Comptt.)**

Solution: $\mu = 1.5$, $R_1 = 20$ cm, $R_2 = -20$ cm, $u = -10$ cm

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$= (1.5 - 1)\left(\frac{1}{20} + \frac{1}{20}\right) = 0.5 \times \frac{1}{10} = 0.05$$

$$\Rightarrow f = \frac{1}{0.05} = 20\ \text{cm}$$

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \Rightarrow \frac{1}{v} = \frac{1}{f} + \frac{1}{u} = \frac{1}{20} + \frac{1}{-10} = -\frac{1}{20}$$

$$\Rightarrow v = -20\ \text{cm}$$

$$\text{Also, } \frac{I}{O} = \frac{v}{u} \Rightarrow I = \frac{-20}{-10} \times 2 = \mathbf{4\ cm}.$$

Hence, the image is virtual, erect and magnified and at a distance of 20 cm.

Example 42. *An object is kept at 0.2 m from a convex lens of focal length 0.15m. Find the position of the image produced.* **(CBSE 1993)**

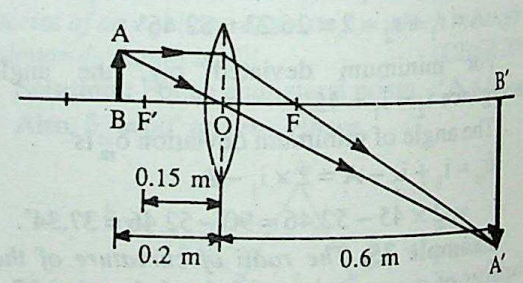
Solution : We have $u = -0.2$ m, $f = +0.15$ m

Now, $$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

$$\Rightarrow \frac{1}{v} = \frac{1}{f} + \frac{1}{u} = \frac{1}{0.15} + \frac{1}{(-0.2)}$$

$$= 6.67 - 5 = 1.67$$

$$\therefore v = \frac{1}{1.67} \approx \mathbf{0.6\ m}.$$



The image formed is, thus, a real image, at a distane of 0.6 m from the lens, on the other side of the lens. The required ray diagram is shown in fig. above.

Example 43. *Find the position of the image formed by a convex lens of 200 mm focal length, when an object is placed (a) 400 mm from it and (b) 150 mm form it.*

Ans. The lens formula is $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

(a) Given, $f = +200$ mm [+ve sign because it is a convex lens]

$u = -400$ mm [–ve sign because object is real], $v = ?$

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$\therefore \frac{1}{v} - \frac{1}{(-400)} = \frac{1}{(+200)}$, $\therefore$ **v = 400 mm**

The image formed is real [because v is +ve] and is at a distance of 400 mm from the lens.

(b) Given, u = – 150 mm, v = ?

$$\frac{1}{v} - \frac{1}{(-150)} = \frac{1}{(+200)}$$

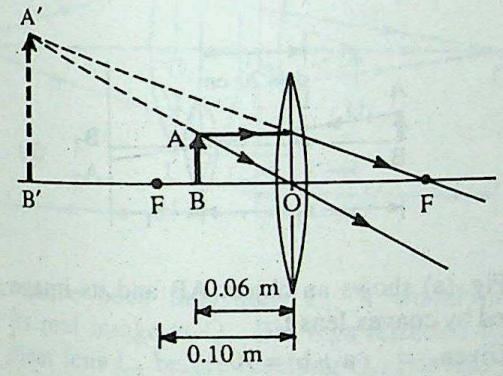
or $\frac{1}{v} = \frac{1}{200} - \frac{1}{150} = -\frac{1}{600}$

or **v = – 600 mm.**

The image formed is now a virtual one.

Example 44. *An object is placed 0.06 m from a convex lens of focal length 0.10 m. Calculate the position of the image.* **(C.B.S.E. 1993)**

Solution : The object is within the focal point of the lens. The image is, therefore, expected to be virtual, erect and enlarged. We have



u = – 0.06 m, f = + 0.10 m

Now $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

Hence, $\frac{1}{v} - \frac{1}{-0.06} = \frac{1}{0.10}$

or $\frac{1}{v} = \frac{1}{0.10} - \frac{1}{0.06} = \frac{100}{10} - \frac{100}{6}$

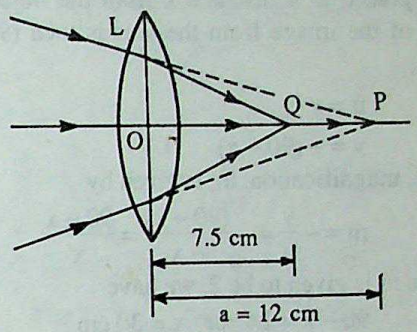
$$\frac{1}{v} = \frac{600 - 1000}{60} = \frac{-400}{60} = \frac{-40}{6}$$

$\therefore$ $v = \frac{-6}{40}$ m = **– 0.15 m.**

The image is, therefore, formed on the same side as the object at a distance of 0.15 m from the lens.

Example 45. *A beam of light converges to a point P. A lens is placed in the path of the convergent beam 12 cm from P. At what point does the beam converge, if the lens is (i) a convex lens of focal length 20 cm, (ii) a concave lens of focal length 16 cm ?*

Solution. (i) Fig. below shows a convex lens L of focal length 20 cm. The incident convergent beam is as shown. Here, P acts as a virtual object at a distance of 12 cm from lens. According to co-ordinate convention of signs,



u = +12 cm, f = + 20 cm, v = ?

From the lens formula,

$$\frac{1}{v} - \frac{1}{(12)} = \frac{1}{20} \text{ or } \frac{1}{v} = \frac{1}{12} + \frac{1}{20} = \frac{5+3}{60}$$

$\therefore$ $v = \frac{60}{8}$ = **7.5 cm.**

The positive sign of v means that image formed is real.

(ii) Fig. below shows a convergent beam incident on a concave lens. According to the co-ordinate convention of signs, u = + 12 cm, f = – 16 cm, v = ?

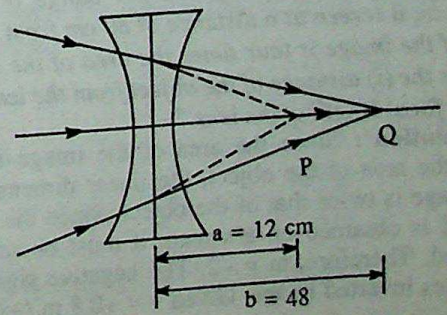
From lens formula

$$\frac{1}{v} - \frac{1}{12} = -\frac{1}{16}$$

or $\frac{1}{v} = \frac{1}{12} - \frac{1}{16} = \frac{4-3}{48}$

$\therefore$ **v = 48 cm**

The positive sign of v indicates that the image of virtual object P is real as shown in fig. above.



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Example 46. *An illuminated object and a screen are placed 90 cm apart. What is the focal length and nature of the lens required to produce a clear image on the screen, twice the size of the object ?*

Solution : Let the required lens be a lens of focal length f placed at a distance x from the object. The distance of the image from the lens is then (90 – x). We have,

$$u = x$$

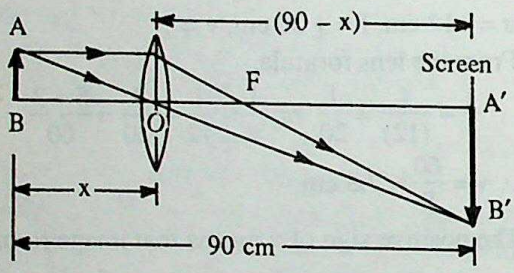
and $$v = +(90 - x)$$

Also, magnification, m, is given by

$$m = -\frac{v}{u} = -\frac{(90-x)}{-x} = \frac{90-x}{x}$$

Since m is given to be 2, we have

$$90 - x = 2x \quad \text{or} \quad x = 30 \text{ cm}$$



Using now the lens formula, *i.e.*, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$, we have

$$\frac{1}{60} - \frac{1}{(-30)} = \frac{1}{f}$$

or $$\frac{1}{f} = \frac{1}{30} + \frac{1}{60} = \frac{3}{60}$$

$$\therefore \quad f = +\mathbf{20\ cm}.$$

The +ve sign indicates that the lens needed is a convex lens. Its focal length must be 20 cm.

Example 47. *A lens forms the image of 1 cm square on a screen at a distance of 80 cm from it. The area of the image is four times the area of the object. What is the (i) distance of the object from the lens, and (ii) the focal length of the lens ?*

Solution : Since the area of the image is four times the area of the object, the linear dimension of the image is twice that of the object. Since the image formed is obtained on a screen, it must be real and inverted. Therefore, m = –2. The negative sign of m indicates inverted image. Given v = +0.8 m (+ve sign because it is a real image). Also, $m = -2 = \frac{v}{u}$

$$\therefore u = -\frac{v}{2} = -\frac{0.8}{2} = -0.4 \text{ m}$$

From the lens formula,

$$\frac{1}{0.8} - \frac{1}{(-0.4)} = \frac{1}{f} \quad \text{or} \quad \frac{1+2}{0.8} = \frac{1}{f}$$

$$\therefore f = \frac{0.8}{3} \text{ m} = \mathbf{0.267\ m}.$$

Example 48. *A screen is placed 90 cm from an object. The image of object on a screen is formed by a convex lens in two different positions separated by 20 cm. What is the focal length of the lens ?*

Solution.

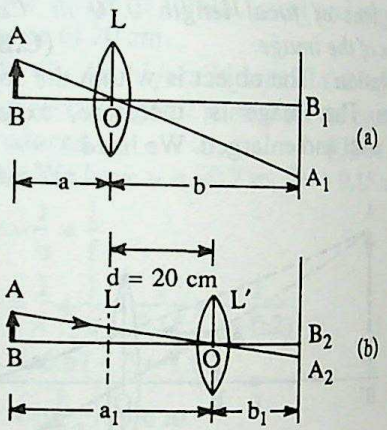


Fig. (a) shows an object AB and its image A_1B_1 formed by convex lens L.

Given, $a + b = 90$ ...(i)

Fig. (b) shows lens in position L′ and image A_2B_2 formed on screen. The object and screen remain unchanged. From the principle of reversibility of light, the object and image distance in fig. (a) and (b) interchange. In other words, a′ = b.

Also, $d = a' - a = 20$ cm.

Therefore, $b - a = 20$ ...(ii)

From eqns (i) and (ii),

$$a = 35 \text{ cm and } b = 55 \text{ cm}$$

According to the co-ordinate convention of signs, u = –35 cm, v = +55 cm. From the lens formula,

$$\frac{1}{55} - \frac{1}{(-35)} = \frac{1}{f} \quad \text{or} \quad \frac{1}{55} + \frac{1}{35} = \frac{1}{f}$$

$$\therefore f = \frac{55 \times 35}{55 + 35} \text{ cm} = \mathbf{21.4\ cm}.$$

Example 49. *An object is placed at a distance of 60 cm from a convex lens of focal length 20 cm. A concave lens of focal length 50 cm is placed co-axially at a distance of 10 cm from the convex lens. What is*

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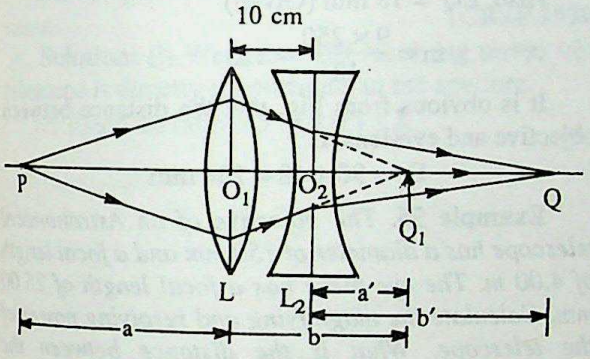
the nature and position of image formed due to refraction at both lens ?

Solution : In fig. below, P is object at a distance a = 60 cm from the convex lens L_1. According to the co-ordinate convention of signs, u = –60 cm, f = + 20 cm. From the lens formula $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$ as applied to L_1, we have

$$\frac{1}{v}-\frac{1}{(-60)}=\frac{1}{(20)}$$

or $\frac{1}{v}=\frac{1}{20}-\frac{1}{60}=\frac{3-1}{60}=\frac{1}{30}$

$\therefore$ **v = 30 cm.**



Had there been only lens L_1, it would have formed its real image at Q_1. But rays refracted from lens L_1 meet lens L_2 before reaching Q_1. For lens L_2, Q_1 acts as a virtual object. For lens L_2,

u′ = 30 – 10 = + 20 cm; f′ = – 50 cm, v′ = ?

From lens formula, as applied to L_2

$$\frac{1}{v'}-\frac{1}{20}=\frac{1}{-50} \text{ or } \frac{1}{v'}=\frac{1}{20}-\frac{1}{50}=\frac{3}{100}$$

$\therefore$ **v′ = + 33.33 cm.**

The positive sign of v′ indicates that the final image Q is real. The image formed is real and at a distance of 33.33 cm from L_2.

Example 50. *Two thin lenses, of focal length 15cm and 30 cm respectively are kept in contact. What is the power of the combined system ?*

(CBSE 1994)

Solution. we have $\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}=\frac{1}{15}+\frac{1}{30}=\frac{1}{10}$

$\therefore$ f = 10 cm = 0.1 m.

$\therefore$ Power, $P=\frac{1}{f}=\frac{1}{0.1}$ diopter

= 10 diopter.

Example 51. *Two thin lenses of focal length + 10 cm and – 5 cm are kept in contact. What is the (i) focal length and (ii) power of the combination ?*

(CBSE 1993)

Solution : The equivalent focal length f of two thin lenses having focal lengths f_1 and f_2 in contact is

$$\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}$$

(i) Given $f_1 = + 10$ cm, $f_2 = – 5$ cm

$$\frac{1}{f}=\frac{1}{10}+\frac{1}{(-5)}=-\frac{1}{10} \Rightarrow \mathbf{-10\ cm}$$

or **F = – 10 cm**

(ii) The power (P) of combination is

$$P=\frac{1}{f\ (\text{in meter})}=\frac{1}{-0.1}=\mathbf{-10\ D}$$

Example 52. *The objective of a telescope is made of a thin convex and a concave lens in contact. The focal length of the objective is 30 cm. If the focal length of concave lens is 60 cm, what is the focal length of the convex lens ?*

Solution : Let f_1 and f_2 be the focal length of the convex and concave lens respectively.

The focal length of combination is f. Then $\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}$. Given,

$$f = +30 \text{ cm},; f_2 = -60 \text{ cm}, f_1 = ?$$

$$\frac{1}{30}=\frac{1}{f_1}+\frac{1}{(-60)}$$

or $\frac{1}{f_1}=\frac{1}{30}+\frac{1}{60}=\frac{3}{60}=\frac{1}{20}$

$\therefore$ **$f_1 = + 20$ cm.**

Example 53. *What must be focal length of a lens used as a simple microscope having a magnifying power of 50. The final image is formed at a distance of 0.25 m from the eye.*

Solution : The magnifying power, m of a simple microscope is

$$m = 1+\frac{D}{f}$$

Given m = 50, D = 0.25 m, f = ?

$\therefore$ $50 = 1+\frac{0.25}{f}$ or $49=\frac{0.25}{f}$

or $f=\frac{0.25}{49}$ **$m = 5.10\times10^{-3}$ m = 5.10 mm.**

Example 54. *A convex lens of focal length 100 mm acts as a simple microscope. At what distance*

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from the lens a object be held so as to view it distinctly with maximum magnifying power ? Is magnification equal to magnifying power ?

Solution : (i) The magnifying power of a simple microscope is maximum, with image seen distinctly, if the image formed is at distance of distinct vision (i.e., 25 cm). Therefore,

$v = -25\text{ cm} = -250\text{ mm}$; $f = +100\text{ mm}$, ?

From the lens formula,

$$\frac{1}{(-250)} - \frac{1}{u} = \frac{1}{100} \text{ or } \frac{1}{u} = -\frac{1}{250} - \frac{1}{100} = \frac{-2-5}{500}$$

$$\therefore u = -\frac{500}{7}\text{ mm} = \mathbf{-71.4\ mm}.$$

The object should be held at a distance of 71.4 mm from the convex lens.

(ii) Since the final image is being formed at distance of distinct vision, the magnifying power and magnification are numerically equal.

Example 55. *A compound microscope is made using a lens of focal length 9 mm as objective and another lens of focal length 18 mm as eye -piece. An object is placed at a distance of 10 mm from the objective and microscope so adjusted that final image is obtained at infinity. Calculate (i) the magnifying power, and (ii) distance between the objective and eye-lens.*

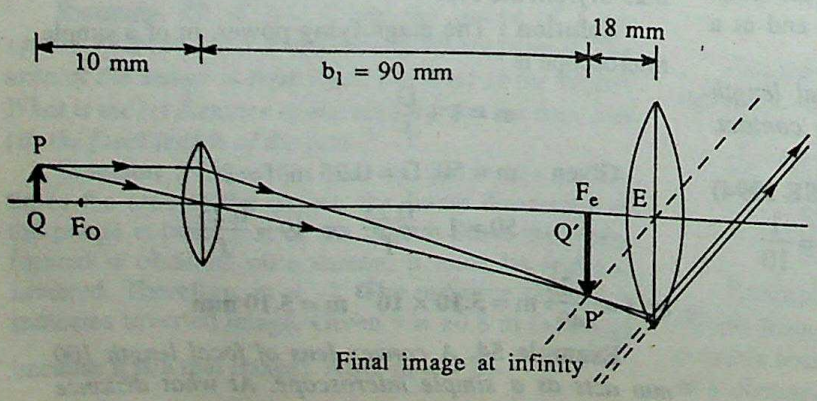
Solution : Let the image formed by objective O be at a distance b_1 from it. Given ,

$u_1 = -10\text{ mm}$, $v_1 = +b_1$; $f_0 = -9\text{ mm}$

Therefore, from lens formula,

$$\frac{1}{(+b_1)} - \frac{1}{(-10)} = \frac{1}{9}$$

$$\text{or } \frac{1}{b_1} = \frac{1}{9} - \frac{1}{10} = \frac{1}{90} \quad \therefore b_1 = 90\text{ mm}$$



Since the final image is formed at infinity this image must be at the focus of the eye-lens. This is shown in fig. below The magnifying power m, by definition is $m = \frac{\beta}{\alpha}$

From fig.

$$\beta = \frac{P'Q'}{EQ'} \text{ and } \alpha = \frac{PQ}{250} \quad [\because D = 250\text{ mm}]$$

$$\therefore \quad m = \frac{P'Q' \times 250}{EQ' \times PQ} \quad \ldots(i)$$

From lens formula

$$\frac{P'Q'}{PQ} = \frac{b_1}{a_1} = \frac{-90}{(-10)} = 9$$

Also, EQ′ = 18 mm (Given)

$$\therefore \quad m = \frac{9 \times 250}{18} = 125$$

It is obvious from Fig. that the distance between objective and eye-lens, is

$$D_1 = 90 + 18 = \mathbf{108\ mm}.$$

Example 56. *The objective of an Astronomical telescope has a diameter of 150 mm and a focal length of 4.00 m. The eye-piece has a focal length of 25.00 mm. Calculate the magnifying and resolving power of the telescope. What is the distance between the objective and the eye-piece ?*

Solution : We are given that

$f_0 = 4.00\text{ m}$, $f_e = 25.00\text{ mm}$, $d = 150\text{ mm}$

$$\therefore \text{ magnifing power, } m = f_o/f_e = \frac{4}{25 \times 10^{-3}} = 160.$$

Also resolving power,

$$\text{R.P.} = 1.22\,\lambda/d = \frac{1.22\,\lambda}{150 \times 10^{-3}} = 8.13\,\lambda$$

Taking wavelength $\lambda = 5500\text{ Å} = 5.5 \times 10^{-7}\text{ m}$, (the region of the green region, the region of maximum sensitivity of the human eye), we have

$$\text{R.P.} = 8.13 \times 5.5 \times 10^{-7}\text{ radian}$$

$$= 44.7 \times 10^{-7}\text{ radian}$$

$$= 44.7 \times 10^{-7} \times (180/\pi) \times 60 \times 60$$

second of arc $\approx$ **0.92″**

The distance between the objective and the eye-piece, in a telescope adjusted to be in its normal adjustment position, equals $(f_o + f_e)$.

Hence, the required distance is

$$d = f_0 + f_e = 4.00\text{ m} + 25 \times 10^{-3}\text{ m}$$

$$= \mathbf{4.025\ m}.$$

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Example 57. *An astronomical telescope consists of two thin lenses set 36 cm apart and has a magnifying power 8. Calculate the focal length of the lenses.* **(CBSE 1997, 1999)**

Solution: $f_0 + f_e = 36$ cm, $m = 8 = \frac{f_0}{f_e} \Rightarrow f_0 = 8\, f_e$

$\therefore f_0 + f_e = 36 \Rightarrow 8f_e + f_e = 36 \Rightarrow f_e = 4$ cm

$\therefore f_0 = 8 \times 4 = \mathbf{32\ cm}$.

Example 58. *The convex lenses of same focal length but of apertures 5 cm and 10 cm are used as objective lenses in two astronomical telescopes.*

(i) What will be the ratio of their resolving power?

(ii) Compare the intensity of image formed in two cases. **(CBSE 1999)**

Solution: (i) We know that resolving power of a telescope is directly proportional to the aperture.

$\therefore$ Required ratio = 5 : 10 = **1 : 2.**

(ii) Ratio of the intensities of the images formed **= 1 : 4.**

Example 59. You are given three lenses having power P and apertures as follows:

$P_1 = 6$ D, $A_1 = 3$ cm;

$P_2 = 3$D, $A_2 = 15$ cm;

$P_3 = 12$ D, $A_3 = 1.5$ cm.

Which two of these will you select to construct (i) a telescope and (ii) a microscope. State the basis for your answer in each case. **(CBSE 1998)**

Solution: (i) For constructing a telescope, the objective should have large aperture and the eye-piece should have small focal length. Hence, lens 2 is suitable for objective and lens 3 is suitable for eye-piece.

(ii) For constructing a microscope, both the objective and the eye-piece should have small focal length and $f_o < f_e$. Hence, lens 3 is suitable for objective and lens 1 is suitable for eye-piece.

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UNIT - X

ELECTRONS AND PHOTONS

CBSE SYLLABUS CONTENTS

Electrical conduction in gases—description of the different patterns observed with decreasing pressure. Production and properties of cathode rays. Thomson's experiment for e/m of electrons, charge of electron by Millikan's oil-drop experiment. Particle nature of light, Einstein's photoelectric equation, Photocells.

No. of periods allotted = 10 out of 168

No. of marks allotted = 10 out of 70 along with Atoms, Molecules and Nuclei.

BASIC FACTS AND FORMULAE

The Conduction of Electricity Through Gases

1. Coulomb and C.T.R. Wilson demonstrated that gases do conduct electricity to some extent at normal pressure.

2. The conduction of electricity through gases has been explained in terms of the ionisation theory of conduction. Under ordinary conditions gases contain ions due to stray ionisation. The gaseous ion move under the influence of external applied field.

3. The number of ions in a gas and hence, its conductivity can be increased by irradiating the gas with external agents like X-rays, ultra-violet light, etc.

The Discharge Tube

4. The gas conduction phenomenon at low pressures is known as *discharge phenomenon.*

5. When the pressure in discharge tube is approximately 10^{-3} mm of mercury, certain rays are emitted normally from the cathode surface. These rays are called cathode rays.

6. Cathode rays are deflected by electric and magnetic fields. These rays are, therefore, charged particles.

The discovery of the Electron

7. The properties of cathode rays were always the same regardless of the material of the cathode or the nature of the gas in the discharge tube. They are, therefore, fundamental gas particles of all atoms. These particles are called *'electrons'*.

Motion of Electrons in Electric and Magnetic field

8. An electron in an electric field is acted upon by a force which is independent of any velocity the electron may have. The force which an electron experiences in an electric field **E** is given by the expression :

$$\mathbf{F} = e\mathbf{E}$$

9. When an electron moves in a electric field, acting at right angles to the direction of motion of electron, it describes a parabolic trajectory.

10. When the lateral deflection suffered by electron is small as compared to the distance it has moved, the trajectory is hardly distinguishable from the *arc of a circle.* Under these conditions, one can write

$$eE = \frac{mv^2}{R_E}$$

where R_E is the radius of the *equivalent circle.*

11. The force which an electron, moving with a velocity v experiences in a magnetic field B, is given by

$$\mathbf{F} = e(\mathbf{v} \times \mathbf{B})$$

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However, when the electron is moving in a direction which is perpendicular to B, the above expression for the force reduces to

$$F = Bev$$

12. The trajectory described by the electron in the above specified condition is an arc of circle. The electron moves in a circular path of radius R_B, such that

$$Bev = \frac{mv^2}{R_B}.$$

13. An electron, moving in crossed electric field (**E**) and magnetic field (**B**) remains undeflected if its velocity v (normal to both **E** and B) has a magnitude v such that

$$v = \left|\frac{E}{B}\right|$$

Thomson's Determination of e/m of Electrons

By studying the deflection of cathode rays in electric and magnetic fields. Thomson determined the value of e/m of the cathode rays.

The e/m of the electron is given by $\frac{e}{m} = \frac{v}{BR}$

where 'R' is the radius of the electron's path in the magnetic field **B**.

14. The deflection in the direction of the electric field, suffered by an electron in covering a distance *l* in the electric field is

$$y = \frac{1}{2}\frac{eE}{m}\left(\frac{l}{v}\right)^2$$

We may use this relation also for determination of e/m.

Determination of the Charge of the Electron

Millikan determined the charge of the electron. He showed that the charge is quantised.

15. According to Stokes' law

$$F = 6\pi\eta r v$$

where F = viscous force, η = coefficient of viscosity of the medium, r = radius of the falling object and v = velocity of the falling object.

16. The charge '*e*' of the electron is determined from

$$e = \frac{6\pi\eta r}{E}\,(v'_E - v_E)_{\text{Minimum}}$$

where,

$$r = \left[\frac{9}{2}\,\frac{\eta v}{(\rho - \sigma)\,g}\right]^{1/2}$$

Here η = co-efficient of viscosity of 'air', r = radius of oil drop, E = applied electric field, ρ = density of oil, σ = density of air, v = terminal velocity of the oil drop in the absence of any electric field; $(v_E' - v_E)_{min.}$ = minimum change in terminal velocity in the presence of the electric field.

The Photoelectric Effect

The photoelectric effect is the emission of electrons from metals when they are illuminated by radiations of appropriate wavelength.

The photoelectric emission depends upon both the nature of the emitter and the quality of light used.

Salient Features of Photo Emission of Electrons

The photoelectric current is directly proportional to the intensity of illumination on the emitter but is almost independent of the frequency of illumination.

The maximum energy with which photoelectrons are ejected from a given metal surface is entirely independent of the intensity of light but depends only on the frequency of light.

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There exists a critical frequency, known as *threshold frequency* for each emitter, below which no photoelectric emission is possible, no matter how strong the intensity of light is.

The photoelectric effect is an instantaneous phenomenon.

Explanation of Photoelectricity

The electromagnetic theory of light is quite incapable of explaining the salient experiment features of photoelectricity.

The phenomenon of photoelectricity was explained by Einstein on the quantum theory of light.

For each radiation of frequency ν, the energy of each quanta is $h\nu$.

According to Einstein's interpretation of photoelectric emission, when light of frequency ν strikes a metal surface, the radiant energy is absorbed in energy quanta of $h\nu$ and this energy is transferred to an electron within the metal.

The Einstein's photoelectric equation is

$$\frac{1}{2} m v_{max.}^2 = h\nu - W_0$$

All the experimental facts of the photoelectricity can be explained on the basis of Einstein's photoelectric equation.

Einstein's photoelectric equation was experimentally verified by Millikan.

SUBJECTIVE QUESTIONS ON UNIT – X

Q.1. *Do gases conduct electricity at normal pressure?* (1)

Ans. Yes; gases do conduct electricity at normal pressure but the conductivity is very small.

Q.2. *Outline the evidence which established that gases conduct electricity.* (2)

Ans. The observed loss of charge, over a period of time, from a solid insulator, led Coulomb to suggest that gases must be regarded as conducting electricity to a small extent. Later experiments, done on a modified form of the gold leaf electroscope, by C.T.R. Wilson confirmed Coulomb's suggestion.

Q.3. *What are the charge carriers in a gas at normal pressure?* (1)

Ans. The charge carriers, in a gas, at normal pressure, are positive ions as well as negative ions.

Q.4. *What are the charge carriers in a gas at very low pressure?* (1)

Ans. The charge carriers in a gas, at very low pressures, are mainly electrons. The negative ions and positive ions also make a small contribution to the conductivity of the gas.

Q.5. *Gases under normal pressure are very poor conductor of electricity but they become good conductor under reduced pressure. Explain.* (2)

Ans. At normal pressure, the gases contain only a small number of positive and negative ions. These, relatively heavier particles, have rather low mobilities and this, coupled with their small number, makes the gases poor conductors. At low pressures, however, we have a large number of free electrons present as charge carriers. These, because of their high mobility, and relatively larger number, make the gases much better conductors at low pressures.

Q.6. *Can the conductivity of a gas be increased by irradiating it with X-rays?* (1)

Ans. Yes; irradiation with X-rays ionizes a large number of atoms and this increases the conductivity of gases.

Q.7. *Can the conductivity of a gas be increased indefinitely by irradiating it with X-rays?* (2)

Ans. No; we cannot expect an indefinite increase in the conductivity by irradiating it continuously with X-rays. This is because we will also have recombination of ions and the rate of recombination will increase with an increase in the number of ions, formed. The gas would, therefore, 'settle down' to some sort of an equilibrium number of ions which would correspond to a certain conductivity'.

Q.8. *In a gas, is the ionisation current directly proportional to the applied potential difference?* (1)

Ans. No; the ionization current varies with the applied p.d. in non-linear way.

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Q.9. *What is the saturation current in a gas?* (1)

Ans. The saturation current corresponds to the maximum current that can flow through the gas, under given conditions, before the phenomenon of ionisation by collision sets in.

Q.10. *What is the electric break down of a gas?* (1)

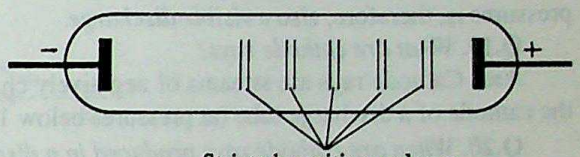
Ans. The electrical breakdown of a gas occurs after the onset of the process of 'ionisation by collision'. At this stage, the gas has such a large number of charge carriers, present in it, that it behaves almost like a perfect conductor.

Q.11. *What is the meaning of discharge through a gas?* (1)

Ans. When the gas has reached a state of an 'electrical breakdown', we speak of there being a *discharge* through the gas. At low pressures, the discharge is also accompnied by a 'glow'.

Q.12. *What is meant by "positive column"?* (1)

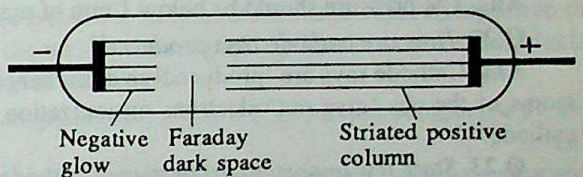
Ans. At very low pressures, about 1-2 mm of Hg, the discharge through the gas is a 'glowing one'. It is, however, non-continuous and there are a number of dark spaces or 'breaks' in between. The glowing portion, near the anode, is broken into a number of *striations* and it is this striated glowing column that occupies a major portion of the discharge tube. We call this striated (long) glowing column as the *positive column.*



Striated positive column

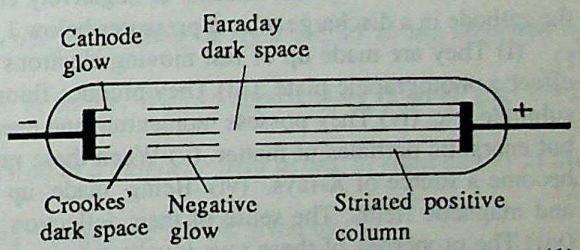
Q.13. *What is Faraday's dark space?* (1)

Ans. At a pressure of about 2 mm of Hg, there is a glow at the cathode, followed by a dark space and then the striated positive column. We call this dark space as the Faraday dark space.



Q.14. *What is Crooke's dark space?* (1)

Ans. At a pressure of about 1 mm of Hg, the negative glow gets detached from the cathode and moves away a little. There is now, a dark space between this negative glow and the glow at the surface of the cathode. We call this dark space as the Crook's dark space is as shown in Fig. alongside.



Q.15. *What are "striations"?* (1)

Ans. The long glowing positive column, filling up the major length of a discharge tube (at low pressures), is not a 'continuous glow'. Rather, it is made up of a number of glowing bands separated by (small) dark spaces. We call this combination of alternate glowing bands and dark spaces as making up the *striations.*

Q.16. *Name the rays that are emitted in a discharge tube when the pressure in the tube is approximately* 10^{-3} *mm of mercury.*

Ans. We get 'cathode rays' in a discharge tube at a pressure of about 10^{-3} mm of Hg. These are made up of negatively charged particles that appear to be 'radiating away' from the cathode.

Q.17. *Compare and contrast the conduction of electricity in an electrolyte and in an ionized gas.* (2)

Ans. The conduction of electricity, through an ionised gas, is similar to that through an electrolyte in that, in both cases, the conduction is due to positive and negative ions. However, the two cases differ in the following respects :

(i) Whereas we need an external ionising agent to ionise a gas, the ions in an electrolyte are formed through the mere process of making the solution.

(ii) The number of ions present in a very dilute electrolyte in far in excess of that in a gas even when it is strongly ionised. Hence, the current in a gas is very low compared to that in an electrolyte.

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Q.18. *Describe the main features of conduction of electricity in gases rendered conducting by an external agent.*

Ans. When a gas is ionised by an external ionizing agent, we get electrons and positive ions produced in the At normal pressures, the electrons soon get attached to a neutral atom and we get negative ions. It is these negative and positive ions that contribute to the gas's conductivity. However, because ion (i) are present in very small numbers and (ii) are not very much mobile, we have only a very low conductivity at these pressures. Further, the ionization current increases with the applied p.d. in a non-linear way.

At low pressures, the mean free path increases and the number of collisions decreases. We, therefore, have quite a large number of free electrons present as charge carriers. The gases, therefore, show a better conductivity at low pressures. Further, the electrons get a 'chance' to get accelerated over a relatively long 'distance' of the applied p.d. Hence, they even acquire the energy to ionize/excite atoms with which they then collide. The ionized/excited atoms, while regaining their normal state, emit light also. The discharge through gases, at low pressures is, therefore, also a *visible discharge.*

Q.19. *What are cathode rays?*

Ans. Cathode rays are streams of negatively charged particles (the electrons) that 'emanate normally from the cathode of a discharge tube (at pressures below 1mm of mercury).

Q.20. *When are cathode rays produced in a discharge tube?*

Ans. Cathode rays are produced in a discharge tube when the pressure is reduced below 1 mm of mercury.

Q.21. *What should be the order of pressure in a discharge tube to produce cathode rays?*

Ans. The pressure should be below 1 mm of mercury.

Q.22. *How are cathode rays produced?*

Ans. Cathode rays are 'produced' in a discharge tube maintained at a pressure below 1 mm of mercury. The atoms of the gas 'give out' electrons on ionization and these electrons 'appear to emanate' normally form the cathode.

Q.23. *State few important properties of cathode rays.*

Ans. Cathode rays are streams of negatively charged particles (the electrons) moving normally away from the cathode in a discharge tube at pressures below 1 mm of mercury. These rays possess the following properties

(i) They are made up of fast moving electrons which are very light negatively charged particles. (ii) They effect a photographic plate. (iii) They produce fluorescence and phosphorescence in suitable materials like zinc sulphide, etc. (iv) They possess momentum and energy and, therefore, (usually) behave like very light, very tiny but energetic particles of matter. (v) When these rays are suddenly stopped by a target, they cause the target to become a source of X-rays. (vi) Being made up of charged particles, these rays are affected by electric and magnetic fields. The sense of their deflection shows them to be made up of negatively charged particles. (vii) The properties of these rays (qualitative as well as quantitative) are the same irrespective of the nature of the gas present in the discharge tube or the metal used for making the electrodes. This indicated that the particles making up these rays are a common constituent of all matter.

Q.24. *What makes us believe that cathode rays are made of electrons?*

Ans. Cathode rays are found to be made up of negatively charged particles. Further, the c/m of these particles is found to be independent of the nature of the gas present or the electrodes used in the discharge tube. Hence, these negatively charged particles must be regarded as a fundamental constituent of all matter. It was these particles that were later on named as the electrons.

Q.25. *Inside a discharge tube producing cathode rays a freely rotatable very light wheel is mounted. What happens when cathode rays fall on the wheel?*

Ans. The wheel starts rotating. This shows that cathode rays have momentum.

Q.26. *How do will you show that cathode rays possess energy and momentum?*

Ans. We can make the cathode rays fall on a very light wheel that is free to rotate. The fact that the wheel starts rotating means that cathode rays possess momentum.

We can also make the cathode rays get focused on a metal piece, say a platinum pieces. The piece then soon becomes red hot. This shows that cathode rays possess energy and their energy has got converted into heat in this set up.

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Q.27. *Is speed of cathode rays same as the speed of light?* **(1)**

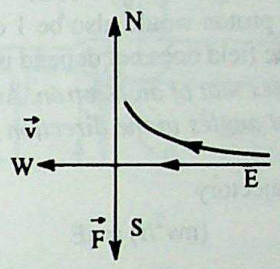
Ans. No; cathode rays are made up of material particles which (even though moving with a very high speed ($\sim 10^7$ ms^{-1}) travel with a speed less than that of light.

Q.28. *Why is sun light not deflected when passed through an electric or magnetic field?* **(1)**

Ans. Sun light is made up of electromagnetic waves (or photons). Electromagnetic waves (or photons) are not affected by an external electric or magnetic field.

Q.29. *Cathode rays, travelling from east to west, enter into the region of electric field, directed from north to south in the plane of the page. In which direction would the cathode rays be deflected?* **(1)**

Ans. The cathode rays would be deflected towards north (i.e., opposite to the direction of the electric field).



Q.30. *How was it established that electron is a fundamental particle of matter?* **(2)**

Ans. The electron is a negatively charged particle whose e/m is found to have the same value irrespective of the (i) nature of the gas present in the discharge tube or (ii) the metal used for making the electrodes. These facts led us to believe that the electron is a fundamental constituent of all matter.

Q.31. *An electron is projected along the direction of a magnetic field. How will its motion be affected by the action of the magnetic field?* **(1)**

Ans. There would be no affect at all. This is because a magnetic field does not exert any force on a charged particle moving parallel to the field direction.

Q.32. *What is the trajectory of an electron in an electric field acting at right angles to the direction of motion of the electron?* **(1)**

Ans. The trajectory of the electron would be *parabolic* in nature. We can approximate (a small part of) it with an arc of a circle.

Q.33. *How one can argue that the trajectory of an electron in a magnetic field acting at right angles to the direction of motion of electron is an arc of circle?* **(2)**

Ans. The force, exerted by a magnetic field, on a moving charged particle, is given by

$$\mathbf{F} = q\,(\mathbf{v} \times \mathbf{B})$$

The force is thus, at all instants, perpendicular to the corresponding instantaneous velocity of the particle (It is also perpendicular to the direction of the magnetic field).

Now, if a particle were to move in a circular path and were to have a radial force acting on it, the force would be normal to the instantaneous velocity at all instants. This is the condition holding for a charged particle moving in a magnetic field. Hence, the path of a charged particle, moving in a magnetic field, can be expected to be circular.

Q.34. *When does a charged particle, entering a magnetic field, describe a helical path?*

Ans. The charged particle describes a 'helical path' when it enters the magnetic field with its initial velocity inclined to the direction of the magnetic field.

Q.35. *The path of cathode rays in an electric field can be approximated to a circle of radius r. In order to double the radius of circular path, how should the electric field be changed? Assume the velocity of the cathode rays remains constant.*

Ans. Let E be the electric field and r the radius of the (approximately) circular path described by charged particles of charge q and mass m.

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$$\therefore \quad \frac{mv^2}{r} = qE$$

or $$r = \left(\frac{m}{q}\right)\frac{v^2}{E}$$

Thus, $r \propto \frac{1}{E}$ for a constant value of v for a given particle beam.

It follows that E should be halved in order to double the value of r.

Q.36. *The mass of a proton is 1847 times that of an electron. What is the gain in kinetic energy of a proton when it is accelerated from rest by a potential difference of 1 volt?* (1)

Ans. The gain in kinetic energy of the proton would also be 1 eV only. The proton has the same charge as the electron and the work done by an electric field does not depend on the mass of the particle.

Q.37. *The mass of a proton is 1847 times that of an electron. An electron and a proton are projected into a uniform electric field in a direction at right angles to the direction of field with same kinetic energy. Which of the two trajectories will be less curved?* (2)

Ans. We have, for the radius *r* of the trajectory

$$(mv^2/r) = qE$$

or $$r = \frac{mv^2}{qE} = \frac{2\,(K.E.)}{qE}$$

We are given that the K.E. is the same for the protons and the electrons. Also *q* for protons is the same as that for electrons. It follows that, in the same electric field, the two particles will then describe circular paths of equal radii.

Q.38. *Define one electron volt.* (1)

Ans. The energy, gained by an electron, when accelerated through a p.d. of one volt, is known as 1 electron-volt (1 eV). Thus,

$$1 \text{ eV} = (1.6 \times 10^{-19} \text{ C}) \times 1 \text{ V} = 1.6 \times 10^{-19} \text{ J}$$

Q.39. *How can the velocity of cathode rays be determined?*

Ans. The cathode rays are subjected to cross electric and magnetic fields. The two fields, besides being perpendicular to each other, are also perpendicular to the velocity of the cathode rays. If the magnitude and directions of the two fields are so adjusted that the particles remain undeflected, we would have

$$qvB = qE \quad \Rightarrow \quad v = E/B$$

We use this relation to find the velocity of the cathode ray particles.

Q.40. *An electron beam passes through a region of crossed electric and magnetic fields of intensity E and B respectively. For what value of electrons speed will the beam remain undeflected?* (CBSE 1995)

Ans. Refer to answer no. 39 above.

Q.41. *What are crossed fields?* (1)

Ans. A pair of electric and magnetic fields, that are acting along mutually perpendicular direction, are known as *crossed fields.*

Q.42. *What is meant by specific charge of an electron?* (1)

Ans. The specific charge of an electron is the ratio of its charge to mass.

Q.43. *What is the value of the specific charge of an electron?* (1)

Ans. The specific charge of the electrons, or its e/m, has the value 1.76×10^{11} C/kg.

Q.44. *Show that the radii of the path of two ions having the same charge and energy but different masses moving in a magnetic field (normal to it) are proportional to the square root of their masses.* (3)

Ans. Let a beam of particles of charge q, mass m, moving with a velocity v, be subjected to a 'normal' magnetic field B. If *r* is the radius of the circular path described by them, we have

$$\frac{mv^2}{r} = qvB \quad \Rightarrow \quad \frac{mv}{qB} = r$$

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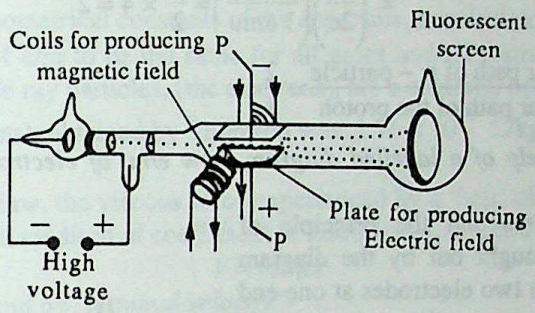
But, mv = momentum = $\sqrt{(2K.E.) \times m}$

$\therefore r = \sqrt{m} \times \frac{\sqrt{2\ K.E.}}{qB}$

Hence, under the given conditions same K.E. and same charge, the radii (in a given magnetic field) are proportional to the square roots of the mass of the charged particles.

Q.45. *Draw a neat labelled diagram of Thomson's experimental set-up for determination of e/m of electrons.* **(CBSE 1995) (2)**

Ans.



Q.46. *An electron, emitted by the cathode of the Thomson tube, passes through mutually perpendicular uniform electric and magnetic fields. Deduce an expression for the velocity with which it reaches the screen undeflected.* **(2)**

Ans. For the electron, to reach the screen undeflected, the force due to the electric and magnetic fields must be equal and opposite to each other.

Let v be the required velocity. Now in a Thomson tube set up, the (initial) direction of motion of the electron and the directions of the electric and magnetic fields are all mutually perpendicular. Hence, the force due to the magnetic field equals Bev. The force due to the electric field is eE. Hence,

$$Bev = eE$$

or $$v = E/B$$

Q.47. *In J.J. Thomson's experiment to determine e/m for electrons, electric field* **E** *and magnetic field of flux density* **B** *are applied. The electron beam is moving with velocity* **v**. *(a) What is the angle between* **E** *and* **B**? *(b) What is the angle between* **v** *and* **B**? **(2)**

Ans. We know that in the J.J. Thomson's experiment, the direction of electron velocity v, the electric field **E** and the magnetic field **B** are all mutually perpendicular to one another. Hence,

(a) angle between **E** and **B** is $\pi/2$ or 90°

(b) angle betwen **v** and **B** is also $\pi/2$ or 90°

Q.48. *Draw a labelled diagram of Thomson's apparatus for measuring e/m of an electron. How is the velocity of electrons determined in this experiment?* **(CBSE 1993) (3)**

Ans. Refer to question no. 45 and 46.

Q.49. *The ratio e/m for a particular kind of positive ion is one half of that for hydrogen nuclei. What can be specific nature of such rays?* **(1)**

Ans. The ratio e/m can be half that of hydrogen provided the charge is 2e and the mass is 4 m. These are the values of the charge and mass of a (singly ionised) *helium ion.* Thus, the given beam of positive ions is likely to be that of *singly ionised helium* ion.

Q.50. *A beam of* α*-particles and of protons, of the same velocity v, enter a uniform magnetic field at right angles to the field lines. The particles describe circular paths. What is the ratio of the radii of these two circles?* **(CBSE 1993 Comptt.) (2)**

Ans. Let particles of charge q and mass m enter a uniform magnetic field B, with a velocity v, at right angles to the field lines. If R is the radius of their circular paths, we have

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$$\frac{mv^2}{R} = Bqv \text{ or } R = \frac{mv}{Bq}.$$

∴ For α-particles and protons, we have

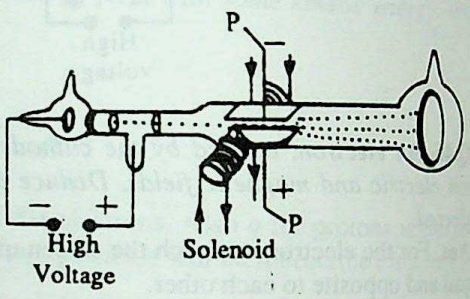
$$\frac{R_1}{R_2} = \frac{m_1 v}{B q_1} \times \frac{B q_2}{m_2 v} = \left(\frac{q_2}{q_1}\right)\left(\frac{m_1}{m_2}\right)$$

$$= \left(\frac{e}{2e}\right)\left(\frac{4 \text{ amu}}{1 \text{ amu}}\right) = \frac{1}{2} \times 4 = 2$$

Thus, $\frac{\text{Radius of the circular path of } \alpha - \text{particle}}{\text{Radius of the circular path of the proton}} = \frac{2}{1}$

Q.51. *Explain, with the help of a labelled diagram, how e/m, of electrons is determined by Thomson's method.* **(CBSE 1994)**

Ans. The essential features and the principle of Thomson's experiment are brought out by the diagram shown. A high voltage between two electrodes at one end of the long evacuated tube shown, produces the cathode rays. The rays are limited to a nearly parallel beam by passing through two slotted cylinders. With no field applied the beam proceeds straight and produces a spot of light on a fluorescent coating inside the large end of the tube.



When the beam is subjected to an electric field produced between the two plates in the mid section of the tube, it gets deflected downward.

Similarly, the application of a magnetic field also deflects the beam and if the field, directed from front to back, it deflects the beam upward. The simultaneous application of the two fields of appropriate strengths and directions can, therefore, leave the beam undeflected.

When this condition is satisfied, we must have

$$F_E = F_B$$

where F_E and F_B are the forces on the cathode ray beam due to the electric and the magnetic field respectively. And since $F_E = eE$ and $F_B = Bev$, we have

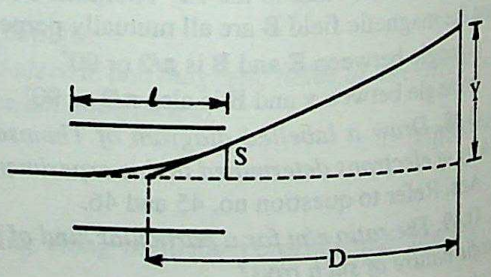
$$Ee = Bev \Rightarrow v = E/B$$

We thus, find v as the ratio of the magnitudes of the 'balancing each other' electric and magnetic fields.

Let us now find the vertical deflection of the beam in an electric field alone.

The vertical acceleration = eE/m

Let '*l*' be the length of the electric field. The beam stays in the field for a time t = *l*/v and its initial vertical velocity is zero. Hence, the vertical deflection at the end of the field is



$$s = \frac{1}{2}\left(\frac{eE}{m}\right)\left(\frac{l}{v}\right)^2$$

The deflection 'y' on the screen at a distance D from the centre of the field, is given by

$$\frac{D}{(l/2)} = \frac{y}{s}$$

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$$\therefore \quad y = \left(\frac{2D}{l}\right)\frac{1}{2}\left(\frac{eE}{m}\right)\left(\frac{l}{v}\right)^2$$

Since we have already determined v, a measurement of y gives us the value of e/m.

$$\therefore \frac{e}{m} = \frac{2y}{E}\left(\frac{v}{l}\right)^2 \frac{l}{2D}$$

This equation can be used to determine e/m. In like manner, one can also use the measured deflection in a magnetic field (alone) and the geometrical constants of the apparatus, to calculate e/m.

Thomson found the value of e/m to be the same for all gases and all materials of the electrodes. He thus, rightly concluded that the cathode ray particles, (the electrons), are a common constituent of all atoms.

The value of e/m (of electrons), obtained by Thomson was 1.76×10^{11} C/kg

Q.52. *State Stokes' law.* **(1)**

Ans. According to **Stoke's law,** the viscous force experienced by a 'ball' of radius 'r', when moving with a velocity v, in an 'infinite' viscous medium of coefficient of viscosity, η, is given by

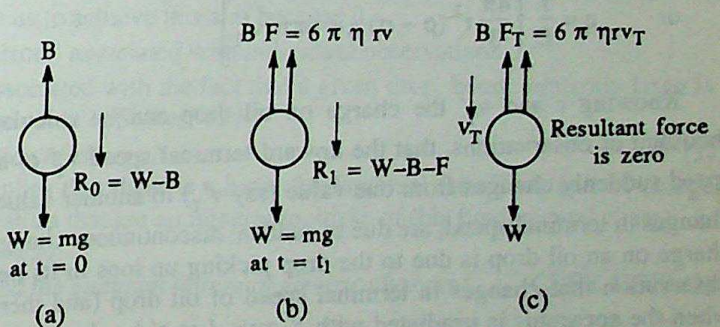
$$F = 6\pi\eta rv$$

Q.53. *What do you understand by "terminal velocity"?* **(1)**

Ans. When a (small) 'ball' falls through a viscous medium, its velocity at first increases because of the gravitational force, (usually) acting on it. The increase in velocity also increases the viscous force acting on the ball. At a particular value of the velocity, the (retarding) viscous force becomes equal and opposite to the net accelerating force (usually the gravitational force) acting on the ball. The net force on the ball then becomes zero and it then 'falls' with a constant velocity. We call this limiting value of the velocity of the ball as its *terminal velocity.*

Q.54. *State the basic principle on which the determination of charge of an electron is based in Millikan's experiment. Give its essential theory.* **(5)**

Ans. Millikan's oil drop experiment makes use of the idea of *terminal velocity* based on Stokes' law.



Consider an oil drop; of mass m and radius r moving freely under gravity. The forces acting on the oil drop are : (a) the weight mg in vertically downward direction and (b) the resistive viscous force F due to presence of air. This force always acts in a direction opposite to the direction of motion of oil drop. The magnitude of this force is given by *Stoke's law.* According to Stoke's law, $F = 6\pi\eta rv$, where v is the instantaneous speed of oil drop, η is coefficient of viscosity and r radius of oil drop. (c) the upward buoyant forces B. The buoyant force equals weight of air displaced. Consider an oil drop starting from rest at t = 0. The force acting are shown in the figure (a) There is no resistive force at t = 0 as v = 0. The resultant force $R_0 = W - B$. The drop has an initial acceleration $a_0 = R_0/m$. As the drop accelerates, its speed increases. A finite resistive force F comes into play. Fig. (b) shows the forces acting at some time $t = t_1$. The resultant force R_1 = W–B–F. Obviously, $R_1 < R_0$. The instantaneous acceleration of drop at $t = t_i$ is $a_1 = R_1/m$.

Clearly $a_1 < a_0$. In other words the drop has a *non-uniform acceleration. The acceleration of drop decreases as time increases.* After a sufficiently long time, the acceleration of drop becomes zero. The drop now moves with a constant speed called the *terminal speed* v_T. The *resultant force on drop, when it has acquired this terminal speed is zero.* This is shown in Fig. (c) Obviously

...(i)

$$B + F_T = W$$

Let ρ and σ denote the density of oil and air respectively. Clearly

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$$W = \frac{4\pi}{3} r^3 \rho g \quad \text{and} \quad B = \frac{4\pi}{3} r^3 \sigma g$$

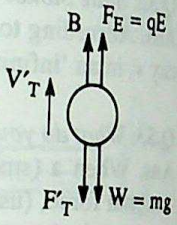
From Eqns. (i) and (ii), we have ...(ii)

$$6\pi\eta r v_T = \frac{4\pi}{3} r^3 (\rho - \sigma) g$$

or $$r^2 = \frac{9}{2} \frac{\eta v_T}{(\rho - \sigma) g}$$

$$r = \left[\frac{9\eta v_r}{2(\rho - \sigma) g}\right]^{1/2} \quad ...(ii)$$

Knowing v_T experimentally, the value of r, the radius of the oil drop is calculated.



Let an external electric field E be applied. Let direction of this electric field be such as to exert a force $F_E + qE$ directed vertically *upwards* on the oil drop. q is the charge on oil drop. Let v_T' be the terminal speed of drop in the presence of applied electric field. The forces acting on the oil drop under these conditions are shown in the figure. The force F_T due to air resistance is now directed vertically downwards. This is because drop is moving in vertically upward direction. Since the drop has acquired terminal speed, the resultant force on it must be zero. Therefore,

$$B + F_E = W + F_T'$$

or $$qE = W - B + 6\pi\eta r v'_T$$

$$= \frac{4\pi}{3} r^3 (\rho - \sigma) g + 6\pi \eta r v'_T$$

or $$q = \frac{1}{E}\left[\frac{4\pi}{3} r^3 (\rho - \sigma) g + 6\pi\eta r v'_T\right] \quad ...(iv)$$

Knowing r and v_T' the charge on oil drop can be calculated from Eqn. (iv) Millikan observed, from thousand of observations, that the upward terminal speed v_T' of a drop does not remain constant. The terminal speed suddenly changes from one value (say v'_T) to another value say v_T''. According to Millikan these sudden changes in terminal speed, are due to sudden, discontinuous changes in the charge on the oil drop. The change in charge on an oil drop is due to the drop picking up ions in its neighbourhood. This fact was confirmed by the observation that changes in terminal speed of oil drop (and therefore, the charge on drop) are more frequent when the apparatus is irradiated with X-rays. Let q′ be charge on oil drop when it has acquired a new terminal speed v_T''. Then according to Eqn. (iv)

$$q' = \frac{1}{E}\left[\frac{4\pi}{3} r^3 (\rho - \sigma) g + 6\pi\eta r v_T''\right]$$

The change in charge,

$$\Delta q = q' - q = \frac{1}{E} 6\pi\eta r [v_T'' - v_T'']$$

The change in charge Δq is directly proportional to change in terminal speed in presence of a given applied electric field. Millikan observed that the change $\Delta v_T = v_T'' - v_T'$, in the terminal speed is always an *integral multiple of a minimum value*. The minimum value of Δv_T [i.e., $(\Delta v_T)_{min.}$] is due to the *smallest change in charge* on the oil drop. All other changes on charge on oil drop are integral multiples of this minimum change. This minimum change of charge was regarded as the electronic charge 'e'. Therefore,

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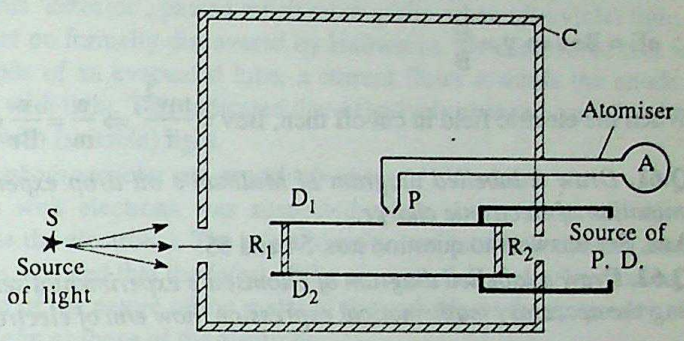
e = charge on electron = $(\Delta q)_{min.} = \frac{6\pi\eta r}{E}(\Delta v_T)_{min.}$ ...(vii)

The mean value of electronic charge found by Millikan was 1.591×10^{-19} C.

Q.55. *Give the experimental details of Millikan's set up for finding the charge of the electron.* **(3)**

Ans. Fig. given alongside shows Millikan's set up. It consists of an observation chamber, made up of optically plane metallic discs D_1 and D_2 about 1.5 cm apart. The discs are held together by insulating rods R_1 and R_2 of glass or ebonite. D_1 and D_2 are perfectly parallel to each other. The upper plate has a fine pin hole P at its centre. The observation chamber is surrounded by a bigger chamber C which is maintained at a constant temperature. Oil drops are produced above pinhole P using an atomiser A. A known strong electric field can be applied between D_1 and D_2. The direction of electric field can be reversed whenever necessary. The space between the observation chamber is strongly illuminated with a suitable source of light. The oil drops in between D_1 and D_2, are observed using a microscope. The drops appear as dark points against a bright background. The drops are generally charged during spraying, due to frictional electricity. The field of view of microscope is graduated. By noting the time taken to travel a known distance, between graduations a known distance apart, the terminal speed is easily calculated.



Q.56. *Why do we take a very large number of observations while determinging the charge of an electron by Millikan's method?* **(2)**

Ans. The charge of the electron is a fundamental constant of nature and has to be determined very accurately. A large number of observations help us to achieve this aim because it

(i) reduces the net effect of the 'random errors' associated with individual observations.

(ii) help us to take into account the error associated with the fact that a given drop, being relatively large in size, is not likely to comply with the assumptions made in Stokes' law.

Q.57. *What do you understand by quantization of charge?* **(1)**

Ans. The term 'quantization' of charge implies that there is a basic fundamental (smallest) unit of charge and, all observed charges in nature, must have values that are an integral multiple of this fundamental charge. In other words, charge can not vary in a continuous way.

Q.58. *Name the experiment which established the quantum nature of electric charges.* **(CBSE 1998) (1)**

Ans. Millikan's oil drop experiment.

Q.59. *An α-particle and a proton are accelerated through the same potential difference. Calculate the ratio of velocities acquired by the two particles.* **(CBSE 1999) (2)**

Ans. Here V is constant,

$\therefore \quad v \propto \sqrt{\frac{q}{m}}$

Now, $v_\alpha = \sqrt{\frac{q_\alpha}{m_\alpha}}$ and $v_p = \sqrt{\frac{q_p}{m_p}}$

$\Rightarrow \quad \frac{v_\alpha}{v_p} = \sqrt{\frac{q_\alpha}{q_p} \cdot \frac{m_p}{m_\alpha}} = \sqrt{\frac{2}{1} \cdot \frac{1}{4}} = \frac{1}{\sqrt{2}}$

$\therefore \quad v_\alpha : v_p = 1 : \sqrt{2}$

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Q.60. *Prove that in Thomson's experiment,* $e/m = \frac{1}{r} \cdot \frac{E}{B^2}$, *where the symbols have usual meaning.*

(CBSE 1999) (2)

Ans. When the beam of electrons passes undeflected through mutually perpendicular electric and magnetic fields, then the forces on the electron due to two fields are equal and opposite.

$\therefore eE = Bev \Rightarrow v = \frac{E}{B}$

When the electric field in cut off then, $Bev = \frac{mv^2}{r} \Rightarrow \frac{e}{m} = \frac{v}{Br} = \frac{E}{B} \cdot \frac{1}{Br} = \frac{1}{r} \cdot \frac{E}{B^2}$.

Q.61. *Draw a labelled diagram of Millikan's oil drop experiment. Discuss the principle involved in the determination of electronic charge.* **(CBSE 1990, 1997 Comptt., 1999) (5)**

Ans. See answers to question nos. 54 and 55.

Q.62. *Draw a labelled diagram of Thomson's experimental set-up to determine e/m of electrons. Explain by deriving the necessary mathematical expression, how e/m of electrons can be determined by this method.*

(CBSE 1998) (5)

Ans. See answers to question nos. 45 and 51.

Q.63. *With the help of a diagram, describe the method to determine the velocity of electrons in J.J. Thomson's experiment.*

If E and B are the intensities of electric and magnetic fields respectively, acting mutually perpendicular to the direction of motion of electron, V the accelerating potential between cathode and anode, prove that $e/m = \frac{E^2}{2VB^2}$

(CBSE 2000) (5)

Ans. See answer to question no. 48.

Potential energy of electron on cathode $= \frac{1}{2} mv^2$

Kinetic energy of electron on anode $= eV$

According to law of conservation of energy $\frac{1}{2} mv^2 = eV$

$\Rightarrow \quad V = \sqrt{\frac{2eV}{m}}$ ...(i)

For undeflected beam of electrons,

Force on electron due to electric field = Force on electron due to magnetic field

$eE = evB \sin 90^\circ \Rightarrow v = \frac{E}{B}$ ...(ii)

From (i) and (ii) $\sqrt{\frac{2eV}{m}} = \frac{E}{B}$

$\Rightarrow \frac{2eV}{m} = \frac{E^2}{B^2} \Rightarrow \frac{e}{m} = \frac{E^2}{2VB^2}$.

Q.64. *In Millikan's oil drop experiment, an oil drop having a charge ne, is held stationary with an external p.d of 400 V. If the size of the drop is doubled, without any change of charge, what p.d. is required to keep the drop stationary?* **(2)**

Ans. For a stationary drop, we have Weight of drop = Electrical force on the drop

Hence, $mg = qE$

If the size, and hence, the weight of the drop, is doubled (without any change in its charge), we would have to double the electric field. Hence, the required new value of p.d. is

$2 \times 400 \text{ V} = 800 \text{ V}$

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Q.65. *What do you understand by photoelectric emission?* **(1)**

Ans. The emission of electrons, by metal surface when light falls on them, is known as photoelectric emission.

Q.66. *How was the phenomenon of photoelectricity discovered?* **(2)**

Ans. The initial discovery of the phenomenon of photoelectricity can be said to have been made by Hertz. He observed that the spark, across the gap of his 'detector', passed much more easily when ultraviolet light was allowed to fall on it. The phenomenon was later on formally discovered by Hallwachs. He discovered that when (suitable) light is allowed to fall on the cathode of an evacuated tube, a current flows towards the anode. No current would flow if the anode was irradiated with light. This indicated that negatively charged particles can get emitted from the cathode when it is irradiated with (suitable) light.

Q.67. *Explain how it was established that photoparticles are negatively charged electrons?* **(2)**

Ans. The identity of the photoparticles with electrons was suspected when it was observed that the photoparticles are also negatively charged (like the electrons). The exact identity was established when Lenard, through his detailed quantitative measurements, showed that the (e/m) of the photoparticles was the same as that of electrons. All the photoparticles irrespective of the nature of the metal of the cathode or the frequency of the irradiating light, always had the same value of e/m as those of the electrons.

Q.68. *Light from a bulb is falling on a wooden table but no photo electrons are emitted. Why?* **(1)**

Ans. Wood is a bad conductor (insulator) and hence, contains no free electrons.

Q.69. *Why are alkali metals most suited as photo- sensitive materials?* **(1)**

Ans. The work function for these metals, being very low, even lights of low frequency can cause photo emission from them.

Q.70. *State the salient features of the phenomenon of photoelectricity.* **(2)**

Ans. Detailed quantitative investigations on the phenomenon of photoelectricity show that this phenomenon has the following salient features :

(i) When light (of suitable frequency) shines on a (sensitive) metal surface, the latter emits electrons.

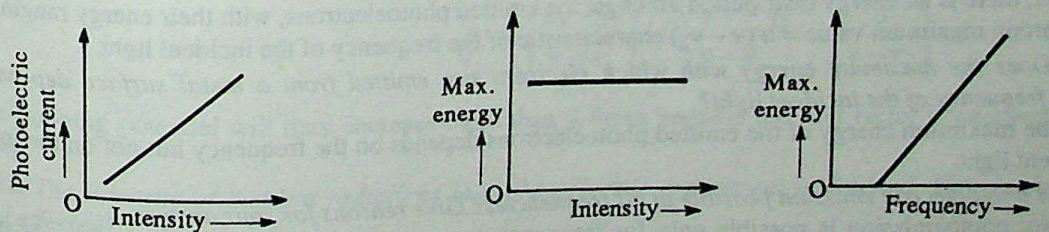
(ii) The phenomenon of photoemission is an instantaneous phenomenon. We start getting emission of photoelectrons 'as soon as' light falls on the metal surface.

(iii) The photoelectric current obtained with a given light (light of a particular frequency) is directly proportional to the intensity of the incident light.

(iv) All the emitted photoelectrons do not have the same energy. There is an energy distribution from zero to certain maximum value, say E_{max}, amongst the emitted photoelectrons.

(v) The maximum energy of the emitted photoelectrons - for light of a given frequency is independent of the intensity of the incident light.

(vi) The maximum energy of the emitted photoelectrons is found to be directly proportional to the frequency of the incident light.



(vii) For each emitting surfaces, there is a (critical) minimum frequency of the incident light below which photoemission from that surface does not take place. We call this minimum frequency as the *threshold frequency* of the given surface.

(viii) We get instantaneous photoemission for incident light frequencies greater than the threshold frequency. This happens even at very low intensities. However, if the incident light frequency is less than the threshold frequency, photoemission does not take place even if very strong intensities are used.

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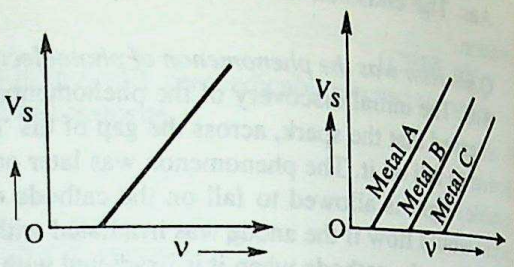
(ix) For a given frequency of the incident light, the photoelectric current becomes zero at a particular (minimum) value of the negative potential of the anode with respect to the cathode. We call this potential as the *stopping potential* for that frequency.

(x) The values of the stopping potential (V_s) for a given surface, are directly proportional to the frequencies of the incident light.

(xi) The *stopping potential* vs *frequency* graphs for different metals all have the same slope but different intercepts on the frequency axis as shown in Fig. above. It means that the graphs for different metals are all straight lines parallel to each other.



Q.71. *What is photoelectric effect? Why it cannot be explained on the basis of wave theory of light?* (CBSE 1994)

Ans. Refer to answer no. 65 for definition of the photoelectric effect.

EM theory's failure vis-a-vis photoelectric effect :

The EM theory could not explain the experimental results on photoelectricity. This is because as per the e.m. theory, *it is the forces, exerted by the electric field of the incident light beam, that bring about an increase in the energy of the free electrons present in the metal.* However the, above mechanism of 'gain of energy by the free electrons from the incident light beam'. does not fit in with the observed features of photoelectricity. This can be seen as follows :

1. The energy of the incident radiation - as per the e.m. theory - must be regarded as smoothly and evenly distributed over its associated wavefront. Hence, each electron would intercept only an insignificantly small amount of energy and would require a finite time (hours, days or weeks) to accumulate enough energy to escape from the metal. Experimentally, however, we observe that electron ejection commences without (any noticeable) delay.

2. The classical wave theory was unable to account for the existence of the threshold frequency. There should be no reason why sufficiently intense beam of low frequency radiation would not be able to produce photoelectricity, if low intensity radiation of higher frequency could produce it.

3. On the classical theory, we expect that light of high intensity, *i.e.*, consisting of strong fields, would give higher kinetic energy to the liberated electrons. This, however, does not happen. Also the electron's energy should not depend particularly on the light frequency. But it does.

It is obvious, therefore, that the photoelectric effect cannot be explained on the basis of the classical e.m. theory of light.

Q.72. *Do all the photoelectrons emitted from a metal surface possess the same energy?* (1)

Ans. No; there is an energy distribution amongst the emitted photoelectrons, with their energy ranging from (zero to a certain maximum value = $h(\nu - \nu_o)$ characteristic of the frequency of the incident light.)

Q.73. *Does the maximum energy with which electrons are emitted from a metal surface depend upon intensity or frequency of the incident light?* (1)

Ans. The maximum energy of the emitted photoelectrons depends on the frequency but not on the intensity of the incident light.

Q.74. *Is photoelectric emission possible at all frequencies? Give reasons for your answer.* (2)

Ans. No; photoemission is possible only for frequencies more than a certain minimum value (called the threshold frequency). This is because the incident photons must have at least the minimum energy equivalent to the work function W of the metal.

Q.75. *What is threshold frequency?* (1)

Ans. The threshold frequency (ν_c) is the minimum frequency of the incident light, for which photoemission is possible, from a given metal surface. It equals (W/h), where W is the work function of the metal concerned. (1)

Q.76. *Does threshold frequency depend on the nature of the emitter?*

Ans. Yes; each emitting surface has a threshold frequency characteristics of the 'emitter' concerned.

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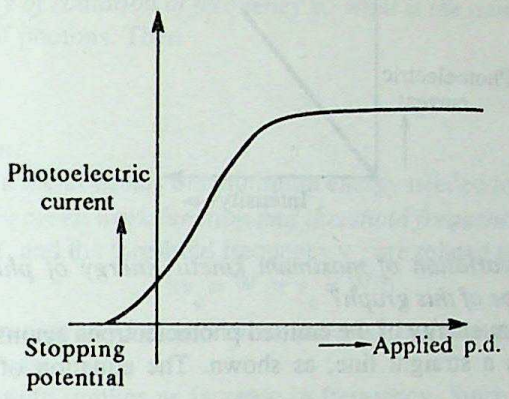
Q.77. *Light of frequency more than threshold frequency is incident on a metal. Draw a graph giving variation of photocurrent with applied p.d.* **(1)**

Ans. The photoelectric current, under these conditions, varies with the applied p.d. in the manner shown.



Q.78. *What is stopping potential?* **(1)**

Ans. The minimum value of the negative potential needed, to completely stop the flow of the photoelectric current, is known as the stopping potential. It depends on the frequency of the incident light, for a given emitter.

Q.79. *The stopping potential for some material is 1.2 V. What is the energy range of the emitted photoelectrons?*

Ans. The range of energies of the emitted photoelectrons will be from 0 to 1.2 eV.

Q.80. *The frequency of radiations ($\nu > \nu_0$) incident a material is doubled. How is stopping potential affected?* **(2)**

Ans.

The stopping potential is related to the frequency for the incident light, by the relation

$$eV_s = h(\nu - \nu_o)$$

$$\therefore \quad V_s = \frac{h}{e}(\nu - \nu_o)$$

On changing the frequency to 2ν, the new stopping potential will be

$$V_s' = \frac{h}{e}(2\nu - \nu_o)$$

$$\therefore \quad \frac{V_s'}{V_s} = \left(\frac{2\nu - \nu_o}{\nu - \nu_o}\right) = \frac{\nu + \nu - \nu_o}{\nu - \nu_o} = \left(\frac{\nu}{\nu - \nu_o}\right) + 1$$

The stopping potential will thus, increase more than 2 times because the first factor is necessarily greater than unity.

Q.81. *The intensity of incident radiations in a photoelectric experiment is doubled. How is the stopping potential affected?* **(1)**

Ans. The stopping potential will remain unaffected because it does not depend on the intensity of the incident light.

Q.82. *If the intensity of the incident radiation on a metal is doubled, what happens to the kinetic energy of the emitted photoelectrons?* **(CBSE 1993) (1)**

Ans. There is no change in the kinetic energy of the emitted electrons. This K.E. is independent of the intensity of the incident radiation as long as its frequency remains the same.

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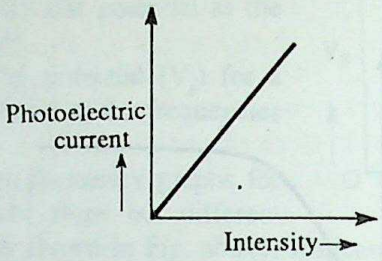
Q.83. *Draw a graph giving variation of photoelectric current with intensity of incident radiations.* (1)

Ans. The graph showing the variation of the photoelectric current, with the intensity of the incident radiation, is of the form shown.

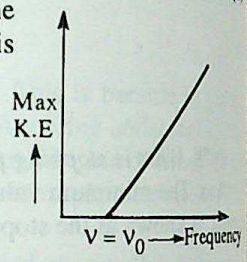


Q.84. *Draw a graph giving variation of maximum kinetic energy of photoelectrons with frequency of incident radiations. What is the slope of this graph?* (2)

Ans. The graph of the maximum energy of the emitted photoelectrons against the frequency of the incident light, is a straight line, as shown. The equation of this straight line is

$$\text{K.E.} = \frac{1}{2} m v^2_{\text{max.}} = h(\nu - \nu_o)$$

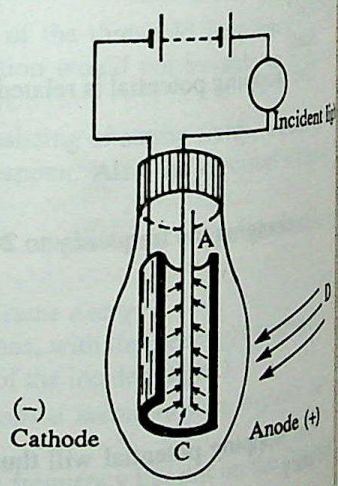
The slope of this graph, therefore, equals h, the Planck's constant.



Q.85. *Explain the functioning of a photocell. Give its two uses.* **(CBSE 1994 Comptt.)** (3)

Ans. A photocell is a practically useful device based on the photoelectric effect. It enables us to change light energy into electrical energy. Now-a-days photocells that work with 'invisible lights', like infrared radiations, ultraviolet rays, etc., are also available.

The early photocells were of the vacuum tube variety. Such a photocell consisted of an evacuated 'bulb' (made of glass for ordinary visible light and, of 'quartz' for ultraviolet radiation) which 'contained' a suitably supported and appropriately sensitive metal plate (to act as the cathode) of a semi-cylindrical shape. The 'metal plate' chosen was such that its threshold frequency was well below the frequencies of 'light' to be used with the photo cell. This was achieved by coating the metal surface with a suitable photo sensitive coating like potassium oxide, caesium oxide or rubidium oxide, etc. The evacuated bulb also had a thin rod of platinum or tungsten to serve as the anode. When light was made to fall on the 'cathode', there was an emission of photoelectrons from its surface. These photoelectrons were attracted towards the anode (maintained at a positive potential with respect to the cathode) and hence, (photoelectric) current flowed in the (external) part of the cathode-anode circuit. We are thus, able to get an electric current (electrical energy flow) from light energy.



For uses of photocells, refer to answer no. 113.

Q.86. *The wavelength of electromagnetic radiation is doubled. What will happen to the energy of the photons?* **(CBSE 1993)** (1)

Ans. We have $E = h\nu = h\,c/\lambda$

Thus, on doubling the wavelength, the energy of the photons will be halved.

Q.87. *Is photoelectric effect an instantaneous phenomenon?* (1)

Ans. Yes; the photoelectric effect is an instantaneous phenomenon with (practically) no time delay between the incidence of light and the start of the photoelectric emission.

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Q.88. *What is the energy of a photon of frequency* ν*?* **(1)**

Ans. The energy of a photon of frequency ν equals $h\nu$, where h is the Planck's constant.

$$(h \approx 6.6 \times 10^{-34}\ \text{J-s})$$

Q.89. *If E is the total energy of radiation of frequency* ν*, what is the number of photoelectrons present?* **(1)**

Ans. Let *n* be the number of photons. Then

$$n.\ h\nu = E$$

or $$n = E/h\nu$$

Q.90. *What is work function?* **(1)**

Ans. The work function of a metal equals the minimum energy needed to cause photoemission from it.

Q.91. *What is the relation between work function and threshold frequency?* **(1)**

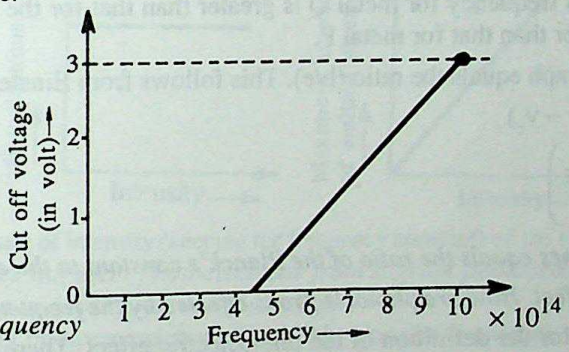
Ans. The work function, W, and the threshold frequency ν_c, are related to each other as

$$h\nu_c = W \text{ or } \nu_c = W/h$$

Q.92. *The wavelength of radiations incident on a material is decreased. Does the maximum velocity of photoelectrons increase or decrease?* **(1)**

Ans. A decrease in wavelength implies an increase in frequency. Since an increase in frequency increases the maximum K.E. of the emitted photoelectrons, the maximum velocity would increase.

Q.93. *For photoelectric effect in sodium, the figure shows the plot of cut off voltage versus frequency of incident radiation. Calculate.*



(i) the threshold frequency

(ii) the work function for sodium. **(CBSE 1995) (2)**

Ans. (i) The threshold frequency corresponds to the frequency for which the cut off voltage is zero. Hence,

Threshold frequency (for sodium) $= 4.5 \times 10^{14}$ Hz

(ii) The work function (W) is related to the threshold frequency (ν_c) by the relation.

$$W = h\nu_c = 6.6 \times 10^{-34} \times 4.5 \times 10^{14}\ \text{J}$$

$$= 29.7 \times 10^{-20}\ \text{J} = 2.97 \times 10^{-19}\ \text{J}$$

$$= \frac{2.97 \times 10^{-19}}{1.6 \times 10^{-19}}\ \text{eV} \approx 1.856\ \text{eV}.$$

Q.94. *What is meant by the work function of a metal? Discuss how the value of work function influences the kinetic energy of the electrons liberated by photoelectric emission.* **(CBSE 1993 Comptt.) (2)**

Ans. The work function of a metal is the minimum external energy, that must be imparted to any of its free electrons in order to enable it to escape from the metal.

Let ν be the frequency of the photons incident on a photoemissive surface. If W is the work function of the metal, the K.E. $\left(= \frac{1}{2} mv^2\right)$ of the emitted electrons is given by $= \frac{1}{2} mv^2 = h\nu - W$ (from Einstein's photoelectric equation.)

It follows that for photons of a given frequency ν (with $h\nu > W$), the kinetic energy of the emitted electrons would decrease with an increase in W and vice-versa. The kinetic energy becomes zero when W equals $h\nu$.

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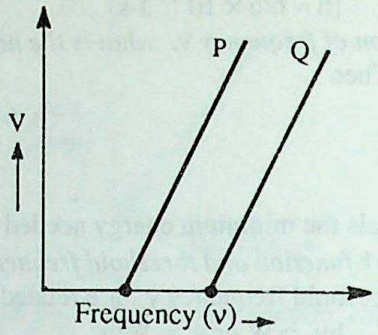
Q.95. *The graph between the stopping potential, V, and frequency ν of the incident radiation, on two different metal plates P and Q are shown in the figure.*



(a) Which metal out of P and Q has the greater value of the work function? (b) What does the slope of the lines depict? **(CBSE 1993 Compt.)**

Ans. (a) The work function, W, of a metal equals $h\nu_c$, where ν_c is the threshold frequency for photoemission from the metal.

Now, the point of intersection of the V vs. ν graph, with the frequency axis, gives the threshold frequency for the metal. Hence, the threshold frequency for metal Q is greater than that for the metal P. It follows then the work function for metal Q is greater than that for metal P.

(b) The slope of the V vs. ν graph equals the ratio (h/e). This follows from Einstein's photoelectric equals.

$$eV = h\nu - W = h(\nu - \nu_c)$$

or $$V = \left(\frac{h}{e}\right)\nu + \left(-\frac{h\nu_c}{e}\right)$$

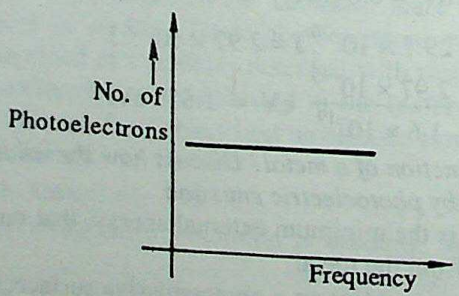
The (common) *slope of the lines equals the ratio of the Planck's constant to the electronic charge.*

Q.96. *Define photoelectric effect. How are photoelectrons effected by the frequency of incident radiation?*

Ans. Refer to answer no. 65 for the definition of the photoelectric effect. There is (practically) no effect of the frequency of the incident radiation on the number of photoelectrons emitted by a phototube.

Q.97. *Sodium is subjected to action of ultraviolet and infra-red radiations one by one and stopping potential determined. Which radiations will have a higher value of stopping potential?* (1)

Ans. The UV radiation will have a higher value of stopping potential as its frequency is (much) more than that of IF rays.



Q.98. *Suppose the photoelectric effect occurs in a gaseous target rather than a solid. Will photoelectrons be produced at all frequencies of the incident photons?* (1)

Ans. No; we are likely to get photoemission only for those frequencies whose photons have an energy equal to or more than the (minimum) ionisation energy for the gas concerned.

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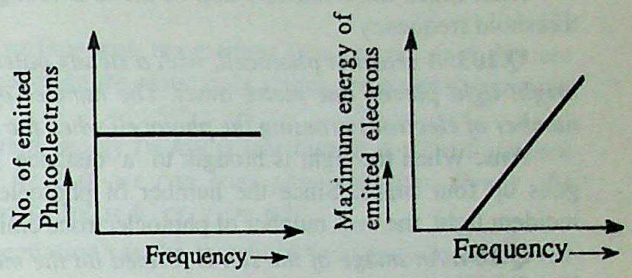
Q.99. *What is photoelectric effect? Explain the effect of increase of (i) frequency (ii) intensity of the incident radiation on photoelectrons emitted by a photo tube.* **(CBSE 1994)**

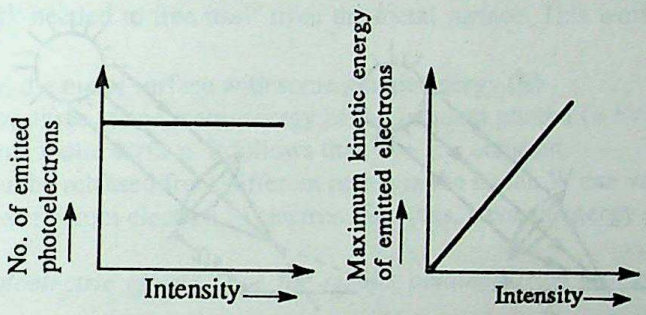
Ans. 'Photoelectric effect' is the phenomenon of emission of electrons from metal surfaces as a result of the incidence of light (of suitable frequency) on them. The electrons thus, emitted are known as photoelectrons.

(i) When the frequency of the incident radiation is made to increase (keeping the intensity constant), there is (practically) no change in the number of electrons emitted but their maximum (kinetic) energy increases in direct proportion to the frequency. These facts are illustrated by the graph given above.



Effects of increase of frequency (keeping intensity constant) on the emitted photoelectrons.

(ii) When the intensity of the incident radiation is made to increase (keeping the frequency constant), there is (practically) no change in their maximum kinetic energy but the number of emitted photoelectrons increases, in direct proportion, to the increase in intensity. These facts are illustrated by the graphs given below.



Effects of increase of intensity (keeping the frequency constant) on the emitted photoelectrons.

Q.100. *Yellow light does not eject photoelectrons from a given photosensitive surface whereas green light does. What shall be situation in case of red and violet light?* **(2)**

Ans. We will not get any photoemission with red light since its frequency is less than that of yellow light.

We will, however, get photoemission with violet light since its frequency is more than that of green light.

Q.101. *By what factor does the maximum velocity of the emitted photoelectrons change when the wavelength of the incident radiation is increased four times? (Given that the initial frequency used is five times the threshold frequency)* **(2)**

Ans. When the wavelength is increased four times, the frequency goes down by a factor of four. Hence, if ν_1 and ν_2 are the initial and final values of maximum velocity, we would have

$$\frac{1}{2} m v_1^2 = h(\nu_1 - \nu_o) \quad \text{and} \quad \frac{1}{2} m v_2^2 = h(\nu_2 - \nu_o)$$

$$\therefore \quad \frac{v_1^2}{v_2^2} = \frac{\nu_1 - \nu_o}{\nu_2 - \nu_o}$$

Now, $\nu_1 = 5\nu_o$ and $\nu_2 = \frac{1}{4}\nu_1 = \frac{5}{4}\nu_o$

$$\therefore \quad \frac{v_1^2}{v_2^2} = \frac{5\nu_o - \nu_o}{(5/4\,\nu_o - \nu_o)} = \frac{4\nu_o}{1/4\,\nu_o} = 16$$

$$\therefore \quad \frac{v_1}{v_2} = 4$$

Thus, the maximum velocity goes down by a factor of 4.

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Q.102. *Two metals A and B were illuminated with appropriate radiations so as to cause photo emission. The work function of metal A is less than the of B. Which metal will have higher value for threshold frequency?* (1)

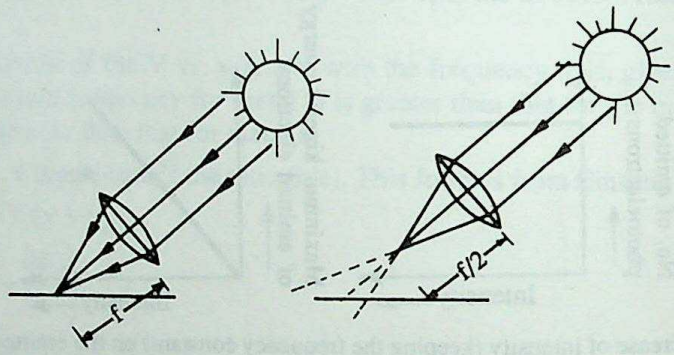
Ans. Since the work function of metal B is higher than that of A, metal B will have a higher value of its threshold frequency.

Q.103. *A ceasium photocell, with a steady potential differenc of 90 volt across it, is illuminated by a small bright light placed one metre away. The number of electrons that cross the photocell is n. What will be the number of electrons crossing the photocell when the same light is placed half metre away?* (2)

Ans. When the light is brought to a distance of 0.5 m, the intensity of the light falling on the photocell goes up four times. Since the number of photoelectrons emitted is directly proportional to the intensity of incident light, the new number of photoelectrons emitted would become 4n.

Q.104. *An image of the sun is formed on the metal surface of photoelectric cell and it produces a current. The lens forming the image is then replaced by another lens of the same diameter but only half in focal length. What will be the effect on the photoelectric current?* (2)

Ans. The focussing action of the lenses in the two cases are shown in Fig. (a) and (b). The sun's rays, after getting focussed earlier, diffuse out again in case (b). Hence, the intensity of light falling on the metal surface gets reduced in case (b) and, we, therefore, get a reduced photoelectric current.



Q.105. *What is a photon?* (1)

Ans. A photon is a quanta *or* a packet of energy. The energy associated with a photon is proportional to the frequency of the incident light. We also assume the rest mass of a photon to be zero.

Q.106. *What is the rest mass of a photon?* (1)

Ans. The rest mass of a photon is assumed to be zero.

Q.107. *Outline the essential ideas of Einstein's interpretation of phenomenon of photoelectricity.*

Ans. Einstein used Planck's ideas of 'photons' to explain the phenomenon of photoelectricity in a simple logical way. He went one step further than Planck when he suggested that

(a) light is not only emitted as separate 'quanta' or photons but also travels through space as a 'beam of photons'.

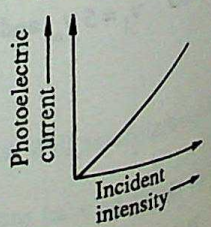
(b) The energy of the light beam is absorbed also in the form of separate quanta or photons.

Thus, when a beam of light strikes a metal surface, it is like a '*rain of photons*' on it. Some of these photons are absorbed by the free electrons present there. All the energy of a particular photon(= hν) is *completely absorbed by only one electron at a time.*

It was on the basis of these ideas that Einstein developed his well known equation for photoelectricity. This equation provides a complete logical explanation of all the observed features of photoelectric effect.

Q.108. *The photoelectric current depends linearly on the intensely of incident light. Explain* (2)

Ans. A photoelectron is released whenever one of the incident photons imparts its total energy to an electron in the metal.



Now, the number of photons associated with a given light beam is a 'measure' of the intensity of the beam. The greater the intensity, the greater is the number of

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photons falling on the metal. We then have a greater number of photonelectron collisions and, therefore, a greater photoelectric current. We thus, see that the photoelectric current is directly proportional to the intensity of the incident light.

Q.109. *Explain the existence of threshold frequency.* **(2)**

Ans. The electrons, that can be released from a metal surface with the greatest ease are the ones that are already on the metal surface. However, even these are released from the metal only if they are given a minimum amount of energy called the work function (ϕ) of the metal.

Suppose, the frequency ν *of a light is such that its photon energy* ($= h\nu$) *is less than* ϕ. *Such a light then cannot release any electron from the metal. However, if* $h\nu \geq \phi$, *we can have photoemission. Hence, the minimum frequency* ν_0 needed to cause photoemission is given by $h\nu_0 = \phi$ or $\nu_0 = \phi/h$

We call ν_0 (the minimum frequency needed for photoemission) as the threshold frequency for the given metal surface.

Q.110. *Explain why there should exist an energy distribution in photoelectrons emitted from a metal surface.* **(2)**

Ans. When a photon collides with an electron, its energy ($= h\nu$) is used by the electron in three steps.

(i) in doing the work needed to come up to the metal surface (W).

(ii) in doing the work needed to free itself from the metal surface. This work is the work function ϕ of the given metal.

(iii) in escaping from the metal surface with some kinetic energy (E).

The sum of the above three terms is the energy of the incident photon ($= h\nu$). Also ϕ (work needed in step (ii) is a constant for a given metal surface. It follows that $W + E =$ constant.

Now, as electrons can be released from different points in the metal, W can vary from electron to electron. It follows that E must also vary from electron to electron. We thus, have an energy distribution among the emitted photoelectrons.

Q.111. *What is photoelectric effect? Give the results obtained from an experimental study of the photo emissive phenomenon?* **(3)**

Ans. See answer to Q. no. 99 for 1st part.

Experiments on photoelectricity provides us with the following results :

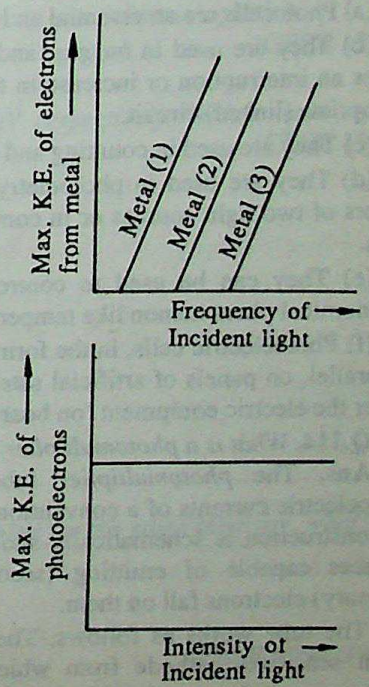
1. A surface shows photoelectric effect only if the incident radiation has a frequency above a certain value called the *threshold frequency*. This frequency is a characteristic of the surface.

2. The emitted photoelectrons have a velocity or energy distribution among them, *i.e.*, they can have different values of these quantities.

3. The maximum energy of the emitted electrons depends only on the frequency of light and has nothing to do with its intensity. The maximum kinetic energy of the emitted electrons increases lineary with the frequency, for frequencies above the threshold value. This result is graphically represented in the figure.

4. For light of a given frequency the photoelectric current is directly proportional to the intensity of light used. This result is represented graphically in figure.

5. If the light of a given frequency can liberate electrons, the emission of photoelectrons is instantaneous. In fact, even for the lowest light intensities, the time interval between incidence of light on the metallic surface and the appearance of electrons is not more than 3×10^{-9} s.



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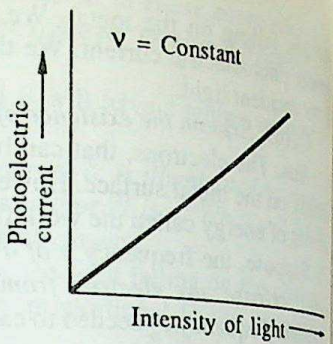
6. Photoelectrons are emitted at light frequencies just above the threshold value, no matter how low the intensity of the light is. Yet, at light frequencies just a bit below the threshold frequency, no electrons are emitted, no matter how high the intensity of the light is.

7. The graphs of maximum kinetic energy of the emitted photoelectrons (*or* stopping potential) against frequency of the incident light, are straight lines for each metal. Further, all these straight lines are parallel to one another, *i.e.*, have the same slope. This is shown in the figure.



Q.112. *Describe in short an experiment to determine the value of Planck's constant using Einstem's photoelectric equation.* (3)

Ans. We know that the maximum energy of the emitted photoelectrons, and hence the stopping potential needed to stop photoemission, both depend on the frequency of the incident light in a linear way. The equation connecting the stopping potential, with the frequency of the incident light, is

$$h(\nu - \nu_{o)} = e V_s$$

$$\therefore \quad V_s = \frac{h}{e}(\nu - \nu_o)$$

If, therefore, a given surface is irradiated with light of different frequencies, and the stopping potential determined in each case, we will get a linear graph. The slope of this straight line graph would equal h/e. Hence if the slope is determined, we can calculate h :

$h = (\text{slope}) \times e$

Thus, one can use Einstein's photoelectric equation to determine the value of the Planck's constant.

Q.113. *List some of the applications of a photocell.* (2)

Ans. Photocells have found a wide variety of applications both in industry and scientific research. We list below some of the applications of these cells :

(a) Photocells are an essential and integral part of the *Television* and *'Phototelegraphy'*.

(b) They are used in *burglar* and *fire alarms*. The interruption or incidence of (additional) light on them causes an interruption or increase in their photocurrent. This change in the current can 'set on' an alarm in an appropriate (linked) circuit.

(c) They are used in counting and automatic control systems.

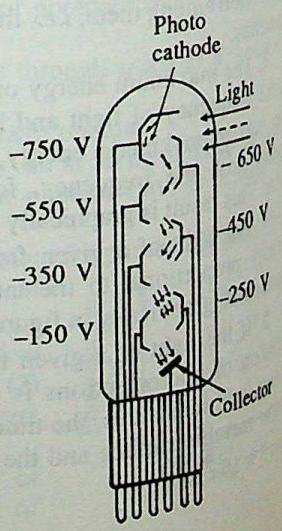
(d) They are used in photometry and complexion meters which can help in comparison of illuminating powers of two light sources or in comparison of colours of different human skins.

(e) They can be used to control furnace temperatures and to study astronomical phenomenon like temperature and spectra of stars.

(f) Photoelectric cells, in the form of solar cells, are connected in series, or parallel, on panels of artificial satellites and space vehicles. They help to power the electric equipment 'on board' such devices.

Q.114. *What is a photomultiplier tube?* (2)

Ans. The *photomultiplier* tube is a device for amplifying the photoelectric currents of a conventional photocell by factors as large as 10^6. Its construction is schematically shown in the figure. It uses a number of surfaces capable of emitting (secondary) electrons when fast moving (primary) electrons fall on them.



The tube works as follows. The incident light is made to fall on the (light sensitive) cathode from which photoelectrons are released. These electrons are then made to accelerate towards the first of the secondary emission surface. The electrons released from this surface 'add up' to the

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incident (primary) electrons and this results in a much stronger electronic current. The process is repeated a number of times and the final electron current reaching the collectror (the anode) is many times (as large as 10^6 times) the original photoelectric current released from the cathode.

The photo multiplier tube, because of its 'built-in' amplification ability, can be used even with very minute light flashes to which an ordinary photocell may not respond 'at all'.

Q.115. *Light from bulb falls on a wooden table but no photoelectrons are emitted. Why?*

(CBSE 1997) (1)

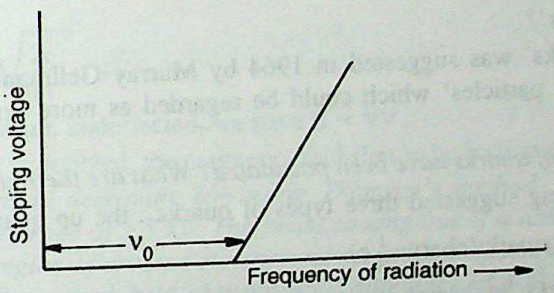
Ans. The energy of light obtained from the bulb is much less than the work function of the wooden blocks. Hence, no photoelectrons are emitted.

Q.116. *Draw a graph showing the variation of stopping potential with frequency of incident radiations in relation to photoelectric effect. Deduce an expression for the slope of this graph using Einstein photoelectric equation.* **(CBSE 1997) (2)**

Ans. See anwer to question no. 70 for 1st part, question no. 95 for 2nd part.

Q.117. *Define the terms threshold frequency and stopping potential for photoelectric effect. Show graphically how the stopping potential, for a given metal varies with frequency of the incident radiation. Mark threshold frequency on this graph.* **(CBSE 1998) (2)**

Ans. See answer to quesstion no. 75 and 78 for 1st part.



Q.118. *Explain laws of photoelectric emission on the basis of Einstein's photoelectric equation.*

(CBSE 1998) (2)

Ans. See Text

Q.119. *Two metals X and Y have work functions 2 eV and 5 eV respectively. Which metal will emit electrons, when it is irradiated with light of wavelength 400 nm and why?* **(CBSE 1999) (2)**

Ans. $\lambda = 400\ \text{nm} = 4 \times 10^{-7}\ \text{m}$

$$\text{Energy of incident light} = h \cdot \frac{c}{\lambda}$$

$$= \frac{6.64 \times 10^{-34} \times 3 \times 10^{8}}{4 \times 10^{-2}}\ \text{J}$$

$$= 4.98 \times 10^{-19}\ \text{J} = \frac{4.98 \times 10^{-19}}{1.6 \times 10^{-19}}\ \text{eV} \approx 3\text{eV}.$$

$\phi_x < 3$ and $\phi_y > 3$

$\therefore$ Metal X will emit electrons.

Q.120. *If the frequency of incident light on a metal surface is doubled for the same intensity, what change would you observe in :*

(i) K.E. of photoelectrons emitted,

(ii) Photoelectric current and

(iii) Stopping potential. Justify your answer in each case. **(CBSE 1998, 1999) (3)**

Ans. (i) $\because$ K.E. $\propto$ V., K.E. of emitted photoelectrons would be doubled.

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(ii) Photoelectric current does not depend upon the frequency of the incident radiation. Hence, it remains the same.

(iii) Stopping potential would also be doubled since it is directly proportional to frequency of incident radiation.

Q.121. *What is photoelectric effect? Explain experimentally the variation of photoelectric current with*
(i) intensity of light
(ii) the p.d. between the plates and
(iii) the frequency of incident light and hence, state the laws of photoelectric emission. **(CBSE 1999)(S)**

Ans. See answer to question 99.

Q.122. *State the dependence of work function on the kinetic energy of electrons emitted in a photocell. If the intensity of incident radiation is doubled, what changes occur in the stopping potential and the photoelectric current.* **(CBSE 2000)(3)**

Ans. According to Einstein theory of photoelectric effect, kinetic energy of emitted electron is

$$E_K = \frac{1}{2} mV_{max}^2 = h\nu - W_0$$

Greater the work function of the metal, lesser the kinetic energy of the photoelectron.

On doubling the intensity of the incident radiation stopping potential remains the same whereas photoelectric current is doubled.

Q.123. *What are 'quarks'?*

Ans. The idea of 'quarks' was suggested in 1964 by Murray Gellmann and George Zweig. They were suggested to be 'elementary particles' which could be regarded as more fundamental than the proton or the neutron.

Q.124. *How many types of quarks have been postulated? What are their charges?*

Ans. Gellmann and Zweig suggested three types of quarks : the up quark (charge $+\frac{2}{3}$ e) the down quark (charge $-\frac{1}{3}$ e) and the strange quark (charge $\frac{1}{3}$ e).

Q.125. *What type of quarks 'make up' a proton?*

Ans. Two up quarks plus one down quark.

Q.126. *What 'quark combination' 'makes up' a neutron?*

Ans. Two down quarks plus one up quark.

Q.127. *The quarks are regarded as having charges that are a fraction of the electronic charge. How is this idea compatible with regarding the electronic charge as the fundamental unit of charge?*

Ans. The quarks are unlikely to be observed as 'free particles'. Charge changes are always observed as an integral multiple of the electronic charge. One can, therefore, still regard the electronic charge as the fundamental unit of charge.

SOLVED NUMERICAL PROBLEMS ON UNIT – X

Example 1. *An electron beam is moving with a velocity of* $3.52 \times 10^7\ ms^{-1}$ *at right angles to a uniform magnetic field of* 10^{-3} *T. What is the radius of the circular arc into which the beam is bent?*

Given : specific charge of electron $= 1.76 \times 10^{11}$ *C/kg*

Solution : We have, in this case, magnitude of the force due to magnetic field = evB.

∴ The required radius is given by $\frac{mv^2}{r} = evB$ or $r = \frac{mv}{eB}$

Substituting values, we get

$$r = \frac{3.52 \times 10^7}{1.76 \times 10^{11} \times 10^{-3}}\ m = 0.2\ m = 20\ cm.$$

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Example 2. *In a Thomson's set-up for determining e/m, the same high tension d.c. supply provides potential to the anode of the accelerating column as also to the positive deflecting plate in the region of crossed fields. If the supply voltage is doubled, by what factor should the magnetic field be increased to keep the electron beam undeflected?*

Solution : Let V be the value of the common potential. When this potential accelerates the electron beam, the velocity acquired is given by

$$\frac{1}{2}mv^2 = eV \text{ or } v = \sqrt{\frac{2eV}{m}} \quad ...(i)$$

The electron beam is undeflected when

$$eE = evB \text{ or } v = E/B \quad ...(ii)$$

But E = V/d. Hence, eqn. (ii) is rewritten as

$$v = \frac{V}{Bd} \quad ...(iii)$$

From eqns. (i) and (iii) we get

$$\sqrt{\frac{2eV}{m}} = \frac{V}{Bd}$$

$$\text{or } Bd\sqrt{\frac{2e}{m}} = \sqrt{V}$$

Thus, for leaving the electron beam undeflected, we have $B \propto \sqrt{V}$.

Thus, when the supply voltage is doubled, the magnetic field should be increased by a factor of $\sqrt{2}$.

Example 3. *In an experiment to determine e/m using Thomson's method, electrons from the cathode accelerate through a potential difference of 1.5 kV. The beam coming out of a hole in the anode is collimated further and then made to enter a region of crossed electric and magnetic fields both perpendicular to the beam direction. Two parallel plates, 2.0 m apart, held at a potential difference of 400 V provide the electric field, while the magnetic field is produced by a Helmholtz coils arrangement. The current in the coils is so adjusted that the beam hits the fluorescent screen at the end of the tube undeflected. The magnetic field due to the coils is calculated to be* 8.6×10^{-4} *T. Determine the charge to mass ratio of the electron.*

Solution : Let v be the velocity of the electron beam after being accelerated through a p.d. of 1.5 kV. The velocity v is given by

$$\frac{1}{2}mv^2 = eV, \text{ or } v = \sqrt{2\,e\,V/m}$$

When this beam remains undeflected under (normal to its velocity) crossed electric and magnetic fields, E and B respectively, we must have eE = Bev or v = E/B

Equating the two values of v, we get $\sqrt{\frac{2eV}{m}} = E/B$ or $\frac{e}{m} = \frac{E^2}{B^2} \times \frac{1}{2V}$

Here $E = 400\ V/(2 \times 10^{-2})\ m = 2 \times 10^4\ Vm^{-1}$, $B = 8.6 \times 10^{-4}$ T and $V = 1.5\ kV = 1.5 \times 10^3\ V$

$$\therefore \frac{e}{m} = \left(\frac{2 \times 10^4}{8.6 \times 10^{-4}}\right)^2 \times \frac{1}{2 \times 1.5 \times 10^3}\ C\,kg^{-1} = \mathbf{1.8 \times 10^{11}\ C\,kg^{-1}}.$$

Example 4. *If an oil drop of weight* 3.2×10^{-13} *N is balanced in an electric field of* 5×10^5 *V/m, find the charge on the oil drop.*

Solution : If q be the charge, we have qE = W

$$\therefore q = \frac{W}{E} = \frac{3.2 \times 10^{-13}\ N}{5 \times 10^5\ V/m} = \mathbf{6.4 \times 10^{-19}\ C}.$$

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Example 5. *Electrons are accelerated through a potential difference of 200 V and then projected at right angle to the field into a magnetic field of 0.01 Wb/m². Calculate the velocity of the electrons on entering the field, and the radius of the circle subsequently described by the electrons.*

Electron charge $= 1.6 \times 10^{-19}$ *coulomb, electron mass* $= 9 \times 10^{-31}$ *kg*

Solution : We can calculate the velocity v of the electron by noting that the work done on the electron equals its kinetic energy. This gives

$$eV = \frac{1}{2}mv^2 \text{ or } v = \sqrt{\frac{2\,eV}{m}}$$

$$\therefore v = \left(\frac{2 \times 1.6 \times 10^{-19} \times 200}{9 \times 10^{-31}}\right)^{1/2} \text{m/s} = \left(\frac{2 \times 1.6 \times 2}{9}\right)^{1/2} \times 10^7 = \mathbf{8.44 \times 10^4\ m/s.}$$

When the electron enters the magnetic field of flux density B, it experiences a force perpendicular to its direction of motion, causing it to move in a circle of radius r such that

$$Bev = \frac{mv^2}{r} \text{ or } r = \frac{m}{e}\frac{v}{B}$$

$$\text{or } r = \frac{9 \times 10^{-31}}{1.6 \times 10^{-19}} \times \frac{8.44 \times 10^4}{0.01} \text{m} = \frac{9.844}{1.6} \times 10^{-4} \text{m} = 4.75 \times 10^{-3} \text{m} = \mathbf{4.75\ mm.}$$

Example 6. *A charged oil drop falls under gravity with a terminal speed v. The drop is held stationary by applying suitable electric field in a Millikan's set-up, and is found to carry 2 excess electrons. Suddenly the drop is observed to move upwards with speed v. Guess what has happened.*

Solution : For the motion of the drop, under gravity alone, we have $6\pi\eta rv = mg$ (v = terminal velocity under gravity alone).

The drop, with a charge 2e, is held stationary by an electric field. The force due to the electric field is thus directed upwards (against gravity) and we must have

(2 e) $E = mg = 6\pi\,\eta\,rv$

The drop would move upwards with a terminal velocity, v, when the force on it due to the electric field (acting upwards) exceeds its weight (= mg) again by an amount $6\pi\eta rv$ (the viscous force). Let this correspond to a charge q on the drop. We then have

$$qE - mg = 6\,\pi\eta\,rv$$

or $qE - 6\pi\eta rv = 6\pi\eta\,rv$ or $qE = 12\,\pi\eta rv$

or since $6\pi\eta rv = 2\,eE$, we have

$$qE = 2 \times 2\ eE = 4\,eE$$

Thus, q = 4 e

The drop thus, [illegible] ing upwards with a terminal velocity, v, when its charge becomes 4e, *i.e.*, it picks up 2 more electrons.

Example 7. *In a given set-up under a fixed electric field, a selected oil drop was made to move upward several times. To cover a distance 0.14 cm it required on an average 71.5, 16.4, 9.2, 6.4 second. Show that these observations are in agreement with Millikan's conclusion.*

Solution : Since the oil drop is moving in a constant electric field, the change in its velocity can be due only to changes in its charge. We should show that the change in the velocities are integral multiples of some minimum change. Let us calculate the various velocities as follows :

Distance travelled = 0.14 cm

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S. No	Time t (second)	Velocity of oil drop $\frac{0.14}{t}$	Change in Velocity
1.	71.5	$\frac{0.14}{71.4} = 1.657 \times 10^{-3}$	
2.	16.4	$\frac{0.14}{16.5} = 8.537 \times 10^{-3}$	6.580×10^{-3}
3.	9.2	$\frac{0.14}{9.2} = 15.72 \times 10^{-3}$	6.683×10^{-3}
4.	6.4	$\frac{0.14}{6.5} = 21.88 \times 10^{-3}$	6.603×10^{-3}

We see that the change in the value of the velocity is approximately same in all the readings and, therefore, the observations are in conformation with Millikan's conclusions.

Example 8. *What is the energy associated in joules with a photon of wavelength 4000 Å?*

Solution : $E = h\nu = \frac{hc}{\lambda}$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{4000 \times 10^{-10}} \text{ J or or } \mathbf{E = 4.95 \times 10^{-19} J.}$$

Example 9. *Obtain the energy in joules acquired by an electron beam when accelerated through a potential difference of 2000 V.*

Solution : The energy (in joule) acquired by an electron (charge = 1.6×10^{-19} coulomb) when accelerated through a potential of V volts is given by $E = eV$

$$E = 1.6 \times 10^{-19} \times 2000 \text{ joule} = \mathbf{3.2 \times 10^{-16} \text{ joule.}}$$

Example 10. *Ultraviolet light of wavelength 800 Å and 700 Å, when allowed to fall on hydrogen atoms in their ground state, is found to liberate electrons with kinetic energy 1.8 eV and 0.4 eV respectively. Find the value of Planck's constant.*

Solution : The energy E is related to wavelength λ, velocity of light c and Planck's constant h by the relation $E = hc/\lambda$.

Hence, $E_1 - E_2 = hc\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right)$

or $$h = \frac{(E_1 - E_2)\lambda_1 \lambda_2}{c(\lambda_2 - \lambda_1)}$$

$$\therefore \quad h = \frac{(1.8 - 0.4) \times 1.6 \times 10^{-19} \times 700 \times 10^{-10} \times 800 \times 10^{-10}}{3 \times 10^{8} \times 100 \times 10^{-10}} \text{ J–s} = \mathbf{6.57 \times 10^{-34} \text{ J–s.}}$$

Example 11. *Ultraviolet light of wavelength 2271 Å, from a 100 W mercury source irradiates a photocell made of molybdenum metal. If the stopping potential is 1.3 V, estimate the work function of the metal. How would the photocell respond to a high intensity (~ 10^5 Wm^{-2}) red light of wavelength 6328 Å produced by a He-Ne laser?*

Solution : The energy of a photon of ultraviolet light of wavelength 2271 Å is $\left(\frac{12420}{2271}\right)$ eV = 5.47 eV

Let W be the work function of the metal. Then, from Einstein's photoelectric equation,

$$5.47 = W + 1.3 \text{ or } W = 4.17 \text{ eV}$$

For red light of wavelength 6328 Å, the energy of a photon is (12420/6328) eV = 1.96 eV. This being less than the work function of the metal, this light cannot cause any photoemission no matter how high the intensity of the source is.

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Example 12. *The work function for the following metals is given*

Na = 1.92 eV, K = 2.15 eV, Mo = 4.17 eV and Ni = 5.0 eV

Which of the metals will not give photoelectric emission for a radiation of wavelength 3300 Å from a He-Cd laser placed 1 cm away from the photocell? What happens if the laser is brought nearer and placed 50 cm away?

Solution : Energy of one photon of radiation of wavelength 3300 Å =(12420/3300) eV = 3.76 eV

This energy is more than the work functions for Na and K but less than those for Mo and Ni. Hence, this radiation cannot cause photoemission from Mo and Ni.

Bringing the laser nearer to the metal surface only increases the intensity of the incident radiation but does not change the energy of the photons emitted at all. Hence, when the laser is brought nearer, we will

(a) observe an increase in the photoelectric current obtained from Na and K but there would be no change in the *stopping potential in either case.*

(b) still not have any photoemission at all from Mo and Ni.

Example 13. *If a photoemissive surface has a threshold frequency of* 4.6×10^{14} *Hz, calculate the energy of the photon in eV.*

Solution : The energy of the photon equals hν. Hence,

$$\text{Energy} = 6.6 \times 10^{-34} \times 4.6 \times 10^{14} \text{ joule}$$

$$= \frac{6.6 \times 4.6 \times 10^{-20}}{1.6 \times 10^{-19}} \text{ eV} = 18.975 \times 10^{-1} \text{ eV} = 1.8975 \text{ eV} \approx 1.9 \text{ eV}$$

Alternatively, we know that

$$2.415 \times 10^{14} \text{ Hz} \Rightarrow 1 \text{ eV}$$

$$\therefore 4.6 \times 10^{14} \text{ Hz} \Rightarrow \frac{1}{2.415} \times 4.6 \text{ eV} \approx \mathbf{1.9 \text{ eV}}.$$

Example 14. *The stopping potential, for a given surface irradiated by a given light, is n volts. What is the maximum energy of the emitted electrons in (a) eV (b) joule?*

Solution : The maximum energy of emitted electrons in electron volt has the same numerical magnitude as is the magnitude of the stopping potential in volt.

Hence, maximum energy (in eV) = n electron volt.

Also $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$

$\therefore$ Maximum energy (in J) = $\mathbf{(1.6 \times 10^{-19} \, n) \, J.}$

Example 15. *What is the energy of a photon of light of wavelength* $n \times 10^3$ *Å ? What must be the maximum value of n in order that we many have photo emission from a surface of work function 2.06 eV?*

Solution :

$$E = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{n \times 10^3 \times 10^{-10}} \text{ J} = \frac{19.8 \times 10^{-19}}{n} \text{ J}$$

$$= \frac{19.8 \times 10^{-19}}{n \times 1.6 \times 10^{-19}} \text{ eV} = \frac{12.4}{n} \text{ eV}$$

We will get photoemission only if

$$\frac{12.4}{n} \geq 2.06 \text{ or } \frac{12.4}{2.067} \geq n \text{ or } 6 \geq n.$$

$\therefore$ The maximum possible value of n is 6 *i.e.,* light of wavelength greater than 6000 Å will not cause photo emission from the given surface.

Example 16. *Light of two different frequencies, whose photons have energies 1 eV and 2.5 eV respectively, successively illuminate a metal whose work function is 0.5 eV. What is the ratio of the maximum speeds of the emitted electrons?*

Solution : We know that maximum energy of the emitted photoelectrons = hν − ϕ.

Hence, $(E_{max})_1 = 1 \text{ eV} - 0.5 \text{ eV} = 0.5 \text{ eV}$

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and $(E_{max})_2 = 2.5\ eV - 0.5\ eV = 2.0\ eV$

$$\therefore \frac{(E_{max})_1}{(E_{max})_2} = \frac{\frac{1}{2} m (v_{max})_1^2}{\frac{1}{2} m (v_{max})_2^2} = \frac{0.5\ eV}{2.0\ eV} = \frac{1}{4}$$

$$\therefore \frac{(v_{max})_1}{(v_{max})_2} = \frac{1}{2}.$$

Example 17. *Light of wavelength 4.125×10^{-7} m falls on a surface of work function 3.5 eV. What can you say about the maximum energy of the emitted photoelectrons?*

($h = 6.6 \times 10^{-34}$ J–s; $c = 3 \times 10^8$ ms^{-1})

Solution : The energy of a photon of the incident light is

$$E = h\nu = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{4.125 \times 10^{-7}} J = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{4.125 \times 10^{-7} \times 1.6 \times 10^{-19}} eV = \frac{6.6 \times 3}{4.125 \times 1.6} eV = 3eV.$$

The work function is 3.5 eV, i.e., greater than the energy of the incident photon. (This means that the frequency of the incident light is less than the threshold frequency for the given surface). Hence, there would be no photoemission in this case.

Example 18. *Work functions of three elements A, B and C are as given below.*

A – 5.0 eV; B – 3.8 eV; C – 2.8 eV

A radiation of wavelength 4125 Å is made to be incident on each of these elements. By appropriate calculations, show in which case photoelectrons will not be emitted. **(CBSE 1998)**

Solution: $\lambda = 4125\ Å = 4125 \times 10^{-10}$ m

Energy of incident radiation, $E = h\frac{c}{\lambda} = \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{4125 \times 10^{-10}} J$

$$= \frac{4.8 \times 10^{-19}}{1.6 \times 10^{-19}} eV = \mathbf{3\ eV.}$$

For photoelectric emission, E should be equal to or greater than the work function. Hence, only element E will emit electrons.

Example 19. *How does the (i) photoelectric current and (ii) kinetic energy of the photoelectrons emitted in a photocell vary if the intensity of the incident radiation is doubled?*

When light of wavelength 300 nm is incident on the cathode of a photocell, the stopping potential recorded is 6V. The wavelength of the incident light increases to 600 nm, calculate the new stopping, potential.

(5) (CBSE 2000)

Solution: (i) Photoelectric current is directly proportional to the intensity of incident radiation. Therefore, photoelectric current gets double.

(ii) K.E. of photoelectrons remains unchanged as it does not depend on the intensity of incident radiation.

$\lambda_1 = 400$ nm, $\lambda_2 = 600$ nm

$V_{S_1} = 6V$, $V_{S_2} = ?$

$$V_{S_1} - V_{S_2} = \frac{hc}{e}\left[\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right]$$

$$6 - V_{S_2} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 10^{-19}}\left[\frac{1}{400 \times 10^{-9}} - \frac{1}{600 \times 10^{-9}}\right] = \frac{6.6 \times 3}{1.6 \times 12} = 1.03$$

$$\Rightarrow \quad V_{S_2} = 6 - 1.03 = \mathbf{4.97\ V}.$$

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Example 20. *The amount of light energy received normally by a unit area is* $1.6 \times 10^2\ Jm^{-2}\ s^{-1}$. *If the mean wavelength of this light is taken as* 4.95×10^{-7} *m, calculate the number of photons striking the unit area is one second.*

Solution : The energy of one photon $= \dfrac{hc}{\lambda} = \dfrac{6.6 \times 10^{-34} \times 3 \times 10^8}{4.95 \times 10^{-7}}\ J = 4 \times 10^{-19}\ J$

Total energy received by the unit area in one second is given to be 1.6×10^2 J. Hence, number of photons striking the unit area, in one second is

$$N = \frac{1.6 \times 10^2}{4 \times 10^{-19}} = \mathbf{4 \times 10^{20}}.$$

Example 21. *Determine the range of wavelengths of the electromagnetic spectrum that can liberate photoelectrons from a surface of work function 2.5 eV.*

Solution : Let λ_m be the threshold wave-length for the given surface. We then have

$$\frac{hc}{\lambda_m} = \varphi \text{ or } \lambda_m = \frac{hc}{\varphi}$$

$$\therefore \quad \lambda_m = \frac{12375}{2.5}\ \text{Å} = \mathbf{4950\ Å}.$$

Photoemission from the given surface takes place for all values of λ for which $0 \le \lambda \le 4950$ Å. Thus, wave lengths *less than and up to 4950 Å can cause photoemission from the given surface.*

Example 22. *When light of wavelength 3094 Å falls on a certain metal surface, the most energetic photoelectrons are stopped by a stopping potential of 2.2 V. On letting light of wavelength 4125 Å fall on the same surface, the corresponding value of the stopping potential is 1.2 V. Use these data values to estimate the value of Planck's constant. (Given* $c = 3 \times 10^8\ ms^{-1}$ and $e = 1.6 \times 10^{-19} C$*)*

Solution : Let φ be the work function of the given surface. Corresponding to incident wave lengths λ_1 and λ_2, we then have, from Einstein's photoelectric equation,

$$\frac{hc}{\lambda_1} = \varphi + e V_1 \text{ and } \frac{hc}{\lambda_2} = \varphi + eV_2$$

$$\therefore \quad hc \left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right) = e (V_1 - V_2)$$

or
$$h = \frac{e (V_1 - V_2) \times \lambda_1 \lambda_2}{c (\lambda_2 - \lambda_1)}$$

Substituting values, we have

$$h = \frac{1.6 \times 10^{-19} \times (2.2 - 1.2) \times 3094 \times 10^{-10} \times 4125 \times 10^{-10}}{3 \times 10^8 \times (4125 - 3094) \times 10^{-10}}\ J\text{–}S$$

$$= \frac{1.6 \times 1 \times 3094 \times 4125 \times 10^{-37}}{3 \times 1031}\ J\text{–}s$$

$$= 1.6 \times \frac{3094}{3093} \times 4.125 \times 10^{-34}\ J\text{–}s$$

$$= \mathbf{6.6 \times 10^{-34}\ J\text{–}s.}$$

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ATOMS, MOLECULES AND NUCLEI

CBSE SYLLABUS CONTENTS

Alpha particle scattering experiment, size of nucleus Rutherford model, Bohr model, energy quantisation, hydrogen spectrum, composition of nucleus atomic masses, size of nucleus. Radioactivity—Alpha, beta and gamma particles/rays and their properties, radioactive decay.

Mass-energy relation. Binding energy and Mass defect. Nuclear fission and fusion, nuclear holocaust.

No. of period alloted : 15 out of 168

No. of marks alloted : 10 out of 70 along with Electrons and Photons.

BASIC FACTS AND FORMULAE

1. The discovery of electron, and the fact that electron is a common constituent of all matter has established the fact that atom has a structure.

Any model of the atomic structure must explain the stability and the spectra of atoms.

2. Thomson's model of the atom

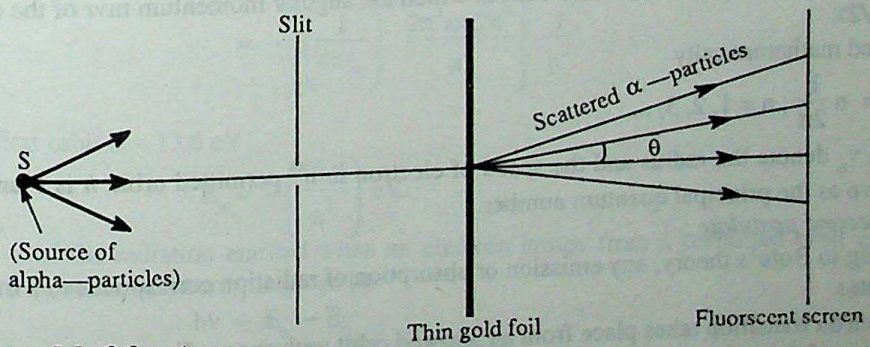
According to Thomson's atomic model, the atom consists of a positively charged substances distributed uniformly over the entire body of the atom, with negative electrons embeded in this sea of continuous positive charge.

3.Scattering of alpha particles

Geiger and Marsden, in their classic experiments on scattering of α-particles, found that most of the α-particles emerged without deviation but some of them were scattered through very large angles.

Rutherford concluded from the results of Geiger and Marsden experiment, that atoms contain a tiny nucleus in which its positive charge and nearly all of its mass is concentrated.

The number of α-particles scattered through an angle θ is proportional to $\frac{1}{\left(\sin^4 \frac{\theta}{2}\right)}$



4. Rutherford's model of the atom

In the Rutherford's model of the atom, the electrons revolve round a stationary nucleus in circular orbits.

The situation is similar to the motion of the earth around the sun. Due to this similarity, Rutherford's model is also known as the planetary model of the atom. The centripetal force, for the motion of the electron round the nucleus, is due to the electrostatic attraction between the electrons and the nucleus.

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Thus, $$\frac{1}{4\pi\varepsilon_0}\frac{Ze\,e}{r^2} = \frac{mv^2}{r}$$

or $$rv^2 = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{m} = \text{constant}$$

The electrons in Rutherford's model can move in orbits of any radius. In other words, orbits of all radii are allowed. Also speed of electron is more if the radius of orbit is small and vice-versa. For an electron in a given orbit,

$$\text{K.E} = \frac{1}{2}mv^2$$

$$\text{P.E} = -\frac{1}{4\pi\varepsilon_0}\frac{(Ze)\,e}{r} = -mv^2$$

$$\therefore \text{ Total energy} = \text{K.E.} + \text{P.E.} = -\frac{1}{2}mv^2$$

Obviously $$\text{K.E} = |\text{T.E}|$$

and $$|\text{P.E.}| = 2\text{K.E.} = 2\,|\text{T.E.}|$$

The negative sign of total energy means that electron is bound to the nucleus. In other words, external energy will have to be given to make the electron move away from the nucleus.

Rutherford's model of the atom has the following two main drawbacks:

(i) The electron moving round the nucleus in a circular orbit, is a charged particle having acceleration (centrepetal acceleration). According to the laws of e.m. theory, the electromagnetic it must lose energy by emitting radiations. As the electron loses energy, the radius of its orbit around nucleus will also decrease. In other words electron follows a spiral path and crash lands into the nucleus. The time taken for this is of the order of a few microseconds only! Therefore, Rutherford's atom is unstable.

(ii) According to Rutherford's model, spectrum of an atom should be a continuous spectrum. Experiments show that atoms have characteristic line spectrum.

5. The Bohr's Model

Bohr modified the Rutherford atomic model by introducing quantum ideas. Bohr's model is based on his two postulates.

Bohr's first postulate:

According to the first postulate of Bohr's theory, the electrons can move only in certain privileged orbits and in these orbits the electrons are prohibited from emitting any electromagnetic radiations. These privileged orbits, known as stationary orbits, are the ones in which the angular momentum mvr of the electron is an integral multiple of $h/2\pi$.

Expressed mathematically

$$mv_n r_n = n\frac{h}{2\pi};\ n = 1, 2, 3, \ldots$$

where r_n and v_n denote the radius and the speed of electron in n^{th} permitted orbit. h is Planck's constant n is an integer, known as the principal quantum number.

Bohr's second postulate :

According to Bohr's theory, any emission or absorption of radiation corresponds to a transition between two stationary states.

If an electron transition takes place from an allowed orbit with energy E_1 to an allowed orbit with energy E_2, the frequency ν of the emitted radiation is given by the relation

$$h\nu = E_1 - E_2$$

6. The Bohr's Formulae

For an electron moving in n^{th} allowed orbit, the angular momentum

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$$m v_n r_n = n \frac{h}{2\pi}$$

Since electron moves in a circular orbit centripetal force = force of attraction due to the nucleus

$$\text{or} \quad \frac{m v_n^2}{r_n} = \frac{1}{4\pi\varepsilon_0} \frac{Ze.e}{r^2}$$

Solving these equations we obtain :

(i) Radii r_n of permitted orbits :

$$r_n = (4\pi\varepsilon_0) \frac{n^2 h^2}{4\pi^2 m Z e^2}$$

The radius r_1 of the first Bohr orbit, for hydrogen, is nearly 0.51Å. Hence,

$r_n = n^2 (0.51)\, Å \quad (n = 1, 2, 3, 4, ...)$

(ii) The velocity v_n of the electron in the nth orbit is

$$v_n = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2\pi Z e^2}{nh}$$

In the first Bohr orbit,

$$v_1 \approx \frac{1}{137} c \; (c = 3 \times 10^8 \text{ m s}^{-1})$$

$$\therefore \quad v_n = \frac{1}{n} \times \left(\frac{1}{137} c \right)$$

(iii) The kinetic and potential energy of the electron in the nth orbit are

$$(K.E.)_n = \frac{1}{2} m v_n^2$$

and

$$(P.E.)_n = -\frac{1}{4\pi\varepsilon_0} \frac{Ze^2}{r_n}$$

(iv) The total energy, E_n of the electron in the nth orbit is

$$E_n = -|K.E.| = \frac{1}{2} \left| (P.E.)_n \right|$$

$$= -\frac{1}{2} \left(\frac{1}{4\pi\varepsilon_0} \right) \frac{Ze^2}{r_n} = -\left(\frac{1}{4\pi\varepsilon_0} \right)^2 \cdot \frac{2\pi^2 m Z^2 e^4}{n^2 h^2}$$

$$= -\left[\left(\frac{1}{4\pi\varepsilon_0} \right)^2 \frac{2\pi^2 m Z^2 e^4}{h^2} \right] \cdot \frac{1}{n^2}$$

The energy in the first orbit is – 13.6 eV

Hence,

$$E_n = -\left(\frac{13.6}{n^2} \right) \text{eV}$$

(v) The frequency ν of the radiation emitted when an electron jumps from a permitted orbit of quantum number n_2, to another of quantum number n_1 is given by

$$h\nu = E_{n_2} - E_{n_1}$$

$$\nu = \left(\frac{1}{4\pi\varepsilon_0} \right)^2 \frac{2\pi^2 m Z^2 e^4}{h^2} \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

(vi) The wave number, $\bar{\nu} \left(= \frac{\nu}{c} = \frac{1}{\lambda} \right)$ of the emitted line is given by

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$$\bar{\nu} = \left(\frac{1}{4\pi\varepsilon_0}\right)^2 \frac{2\pi^2 mZ^2 e^4}{ch^3}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

$$= R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

where $R = \left[\left(\frac{1}{4\pi\epsilon_0}\right)^2 \cdot \frac{2\pi^2 m Z^2 e^4}{ch^3}\right]$ known as the Rydberg constant.

7. The spectrum of hydrogen atom

The wave numbers of the spectral lines in the various series of hydrogen spectrum are

(i) *Lyman series:*

$$\bar{\nu} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right); \quad n = 2, 3, 4, \ldots.$$

(ii) *Balmer series:*

$$\bar{\nu} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right); \quad n = 3, 4, 5, \ldots$$

(iii) *Paschen series :*

$$\bar{\nu} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right); \quad n = 4, 5, 6, \ldots$$

(iv) *Brackett series :*

$$\bar{\nu} = R\left(\frac{1}{4^2} - \frac{1}{n^2}\right); \quad n = 5, 6, 7, \ldots$$

(v) *Pfund series:*

$$\bar{\nu} = R\left(\frac{1}{5^2} - \frac{1}{n^2}\right) \quad (n = 6, 7, \ldots)$$

The longest wavelength for each series corresponds to the least value of n for that series, e.g,

$$\bar{\nu}_L = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right) \text{ for Balmer series} = \frac{5}{36}R$$

$$\therefore \quad \lambda_L = \frac{36}{5R} \text{ for Balmer series}$$

The shortest wavelength limit for each series corresponds to $n \to \infty$. Hence,

$\bar{\nu}_s = R$ for Lyman series = R/4 for Balmer series and so on

8. The energy level diagram

The total energy of electron in n^{th} allowed orbit, in hydrogen atom is

$$E_n = -\frac{13.6}{n^2} \text{ eV}$$

$\therefore$

$$E_1 = -13.6 \text{ eV}$$

$$E_2 = -\frac{13.6}{(2)^2} = -3.4 \text{ eV}$$

$$E_3 = -\frac{13.6}{(3)^2} = -1.51 \text{ eV}$$

$$E_4 = -\frac{13.6}{(4)^2} = -0.85 \text{ eV}, \ldots E_\infty = 0$$

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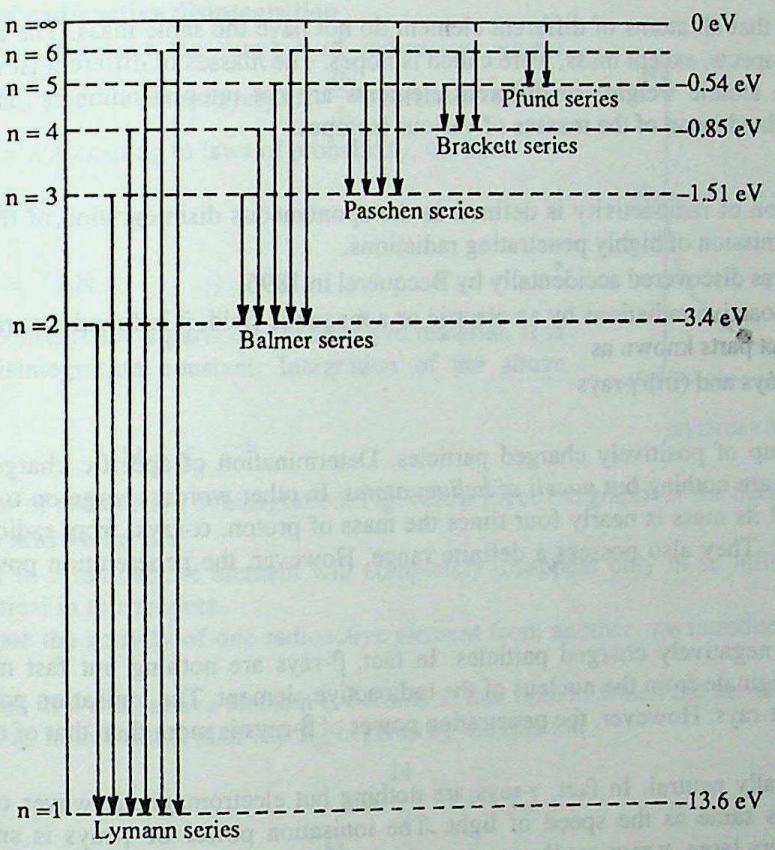
The energy level diagram is a diagram in which each permitted energy state is represented by a straight line. On the left hand-corner of line the value of principal quantum number *n* is written. On the *right hand* corner the value of total energy of that level is written. The distance between any two lines, equals the energy difference between the two states concerned, on a convenient scale. Figure shows the energy-level diagram of the hydrogen atom. The various transitions are represented by vertical arrows. They start from the initial high energy state from which the electron jumps at the state to the which electron comes. The various transitions corresponding to different series in the spectrum of hydrogen are shown in the figure below.



Bohr theory could successfully explain the spectra of various series in the hydrogen spectra.

Bohr theory, however, could not explain the fine structure of spectral lines.

9. The whole number Rule

According to Prout's hypothesis, the mass of all elements can be expressed as an integral multiple of the mass of hydrogen.

This means that there is same basic building block and all atoms are made by collection of a finite number of these blocks.

10. The Bainbridge's mass spectrometer

A beam of positive ions of different masses and speeds is subjected to the action of simultaneous and mutually perpendicular electric and magnetic fields. Positive ions of different masses, but a particular speed v, travel in a straight line. For these positive ions, the force due to the electric and magnetic fields are equal in magnitude and opposite in direction. Therefore

$$eE = Bev \quad \text{or} \quad v = E/B$$

This arrangement is known as a *"velocity selector."*

These positive ions of same speed but different masses are made to describe a semi-circular path in a perpendicular magnetic field *B*. Let R be radius of circular path of ions of mass m. Then

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$$\frac{mv^2}{R} = Bev$$

or $$R = \frac{mv}{Be}$$

Since, v, B and e are same for all positive ions, so $R \propto m$. Bainbridge used this set-up and determin accurately masses of different atoms.

11. Isotopes

Bainbridge found that all atoms of different element do not have the same mass. The atoms of an elem identical in all other respects, except mass, were called isotopes. The masses of different isotopes are very nea integral numbers. The atomic weights of different elements are not integral numbers. The atomic weight considered as the weighted mean of the masses of various isotopes.

12. Radioactivity

1. The phenomenon of radioactivity is defined as the spontaneous disintegration of the nucleus of one more atoms with the emission of highly penetrating radiations.

2. Radioactivity was discovered accidentally by Becquerel in 1896.

By deflecting radioactive radiations by an electric or a magnetic field, it is found that radioactive radiatio consists of three distinct parts known as

(i) α– rays (ii) β-rays and (iii) γ-rays

(i) α – *rays* :

α-rays are made up of positively charged particles. Determination of specific charge (= charge / mas shows that α-particles are nothing but *nuceli of helium atoms.* In other words, charge on α-particle is twice th charge on electron and its mass is nearly four times the mass of proton. α-rays, from radioactive sources ha large ionisation power. They also possess a definite range. However, the peneteration power of α-particles small.

(ii) β-*rays* :

β-rays consist of negatively charged particles. In fact, β-rays are nothing but fast moving electrons. radioactivity β-rays originate from the nucleus of the radioactive element. The ionisation power of β-particles small as compared to α-rays. However, the penetration power of β-rays is more than that of α-rays.

(iii) γ-*rays* :

γ-rays are electrically neutral. In fact, γ-rays are nothing but electromagnetic waves of short wavelengt The speed of γ-rays is same as the speed of light. The ionisation power of γ-rays is small, however, the penetration power is very large. γ-rays are the most energetic electromagnetic waves known.

13. Rutherford and Soddy's law

According to Rutherford and Soddy's theory, whenever a radioactive disintegration occurs, it does so with the emission of either an α particle or a β particle.

A particular atom disintegrates by either emitting an α-particle or a β-particle but not both simultaneously. When a radioactive nucleus emits an α-particle (${}_2^4He$), the resulting daughter nucleus and the parent nucleus are related as

$${}_Z^AX \rightarrow {}_2^4He + {}_{Z-2}^{A-4}Y$$

When a radioactive nucleus emits a β–particle $\left({}_{-1}^{0}e\right)$, the resulting daughter nucleus and parent nucleus are related as

$${}_Z^AX \rightarrow {}_{-1}^{0}e + {}_{Z+1}^{A}Y$$

For positron (${}_{+1}^{0}e$) emission, the relation between the parent and daughter nuclei is

$${}_Z^AX \rightarrow {}_{+1}^{0}e + {}_{Z-1}^{A}Y$$

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In radioactive transformations, it is observed that the daughter from a given parent is also usually radioactive. The daughter further changes to a new element by α or β emission. This chain continues until a stable element, usually an isotope of lead, is reached. Such a chain of radioactive changes constitute a radioactive series. The four well known radioactive series are :

(i) Uranium series (ii) Actinium series, (iii) Thorium series and (iv) Neptunium series.

The first three series end on a stable isotope of *lead*. However, the fourth series ends on a stable isotope of bismuth.

14. The law of radioactive disintegration

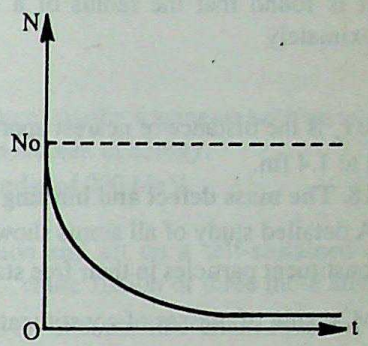
Let N_0 and N represent the number of radioactive atoms present at t = 0 and at t = t respectively. If $\frac{dN}{dt}$ represents rate of disintegration at t = t, according to laws of probability, we have

$$\frac{dN}{dt} \propto N$$

or $$\frac{dN}{dt} = -\lambda N$$

Here λ is a constant for a particular radioactive material. It is known as the disintegration constant. Integration of the above equation gives

$$N = N_0 e^{-\lambda t}$$



(a) Decay of radioactive atom

This is the law of radioactive disintegration. Fig. below gives the graph for the decay of a radioactive atom.

15. Half-life and Mean life

Radioactivity in a radioactive element will completely disappear only in an infinite time. All radioactive elements are identical in this respect.

To differentiate the activity of one radioactive element from another, we introduce the concept of half life and mean-life.

(i) *The half-life* of a radioactive element is defined as that time in which the number of radioactive atoms is reduced to half of its initial value. Half life $T_{1/2}$ is given by the relation

$$N = \frac{N_o}{2} \text{ at } t = T_{1/2}$$

$$\therefore \quad \frac{N_o}{2} = N_o e^{-\lambda T_{1/2}}$$

or $$T_{1/2} = \frac{0.693}{\lambda}$$

The *mean life* is defined as the ratio of the combined age of all the atoms and the total number of atoms in the concerned sample. Mean life is given by the relation.

$$\tau = \frac{\sum \text{total of lives of all radioactive atoms}}{\text{number of radioactive atoms}}$$

$$= \frac{\int_0^\infty t dN}{\int dN} = \frac{N_o \int_o^\infty t e^{-\lambda t} dt}{N_o} = \frac{1}{\lambda}$$

16. Artificial radioactivity

Radioactivity can be induced by bombarding light nuclei with α-particles. In artificial radioactivity positrons are emitted. The positron activity was again found to decrease with time according to an exponential law.

Radioisotopes are used in tracer technique, in agriculture, and in radio-carbon dating among others.

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17. The atomic nucleus

According to Rutherford, the atom has a small positively charged nucleus. Practically the whole mass of the atom is concentrated in this nucleus.

The nucleus consists of protons and neutrons. Neutrons were discovered by Chadwick in 1932.

According to the neutron–proton hypothesis, a nucleus ${}^{A}_{Z}X$ consists of z-protons and (A – z) neutrons, i.e.,

${}^{A}_{Z}X$ = z protons + (A – z) neutrons

z is known as the atomic number and A is mass number.

It is found that the radius of a nucleus varies as the cube root of its mass number. It is found that approximately

$$r = r_o A^{1/3}$$

where r_o is the distance of nearest approach to the nucleus. r_o is referred to as nuclear unit of radius and is nearly equal to 1.4 fm.

18. The mass defect and binding energy

A detailed study of all atoms shows that the actual atomic mass is always less than the sum of the masses of the constituent particles in their free state. Consider the nucleus of atom ${}^{A}_{Z}X$. Let M be the mass of the nucleus.

M′ = sum of masses of constituents of nucleus ${}^{A}_{Z}X$

$= Z\, m_p + (A - Z)\, m_n$

where m_p and m_n denote mass of proton and neutron respectively. It is found that $M' > M$. The difference between M′ and M is known as the mass defect.

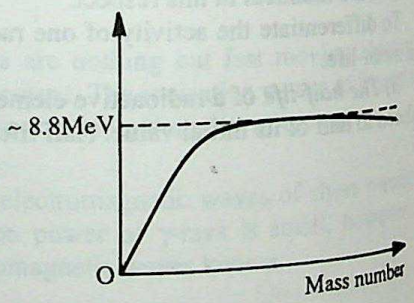
Mass defect = Δm = sum of masses of nucleons of ${}^{A}_{Z}X$ – actual mass of ${}^{A}_{Z}X$ = M′ – M

In other words; the formation of an atom from its constituents always results in disappearance of mass. This mass appears in the form of energy. This energy is known as the binding energy. We can also define binding energy as the energy needed to break the nucleus into its constituent particles.

According to Einstein's mass-energy equivalence relation,

Binding energy = mass defect × c^2; where c is the speed of light in vacuum.

Calculations of B.E. and B.E. per nucleon show that B.E per nucleon is more for stable atoms Figure shows variation of B.E./nucleon with the mass number.



The B.E / nucleon for most of stable atoms is nearly 8.8 MeV.

19. Nuclear reactions

When a given nucleus ${}^{A}_{Z}X$ is bombarded with an appropriate high energy particle a new nucleus ${}^{A'}_{Z'}Y$ is formed. This process is known as a nuclear reaction. In a nuclear reaction; in general, the sum of masses of reactants (M) and the sum of masses of the products (M′) is not same. The difference (M – M′) is known as mass defect of the reaction. A nuclear reaction results in release of energy (i.e., is *exothermic*) if M – M′ is positive. On the other hand, energy is absorbed in a nuclear reaction (i.e., process is *endothermic*) if (M – M′) is negative.

Studies of B.E./nucleon vs mass number curve shows that energy is released in a nuclear process, if B.E./nucleon of products is more than in B.E. per nucleon of reactants and vice-versa. Therefore, fission (or breaking up) of heavy nucleus and fusion (joining together) of light nuclei both result in release of energy.

20. Nuclear fission

When uranium was bombarded with neutrons, Fermi found that a compound nucleus is formed (due to neutron capture) along with the emission of β particles with a number of different half lives. He interpreted this phenomenon as the formation of transuranium elements.

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Hahn and Strassman, after a series of careful chemical analyses of the products formed, when uranium was bombarded with neutrons, established that uranium nucleus after the capture of a neutron seemed to be splitting apart into two nearly equal fragments.

Lise Meitner and R. Frisch, suggested that the neutron initiated a decomposition of the uranium nucleus in two nuclei of roughly equal size. The phenomenon was termed as nuclear fission.

The more common fission reactions are :

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{144}_{56}Ba + ^{89}_{36}Kr + 3\ ^{1}_{0}n + Q$$

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{133}_{51}Sb + ^{99}_{41}Nb + 4\ ^{1}_{0}n + Q$$

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2\ ^{1}_{0}n + Q$$

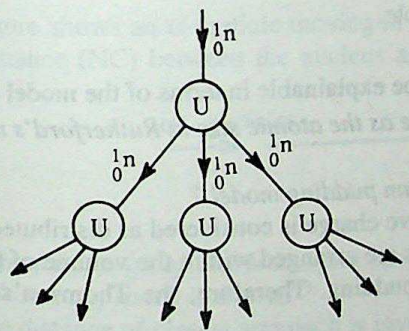
Due to fission, a uranium nucleus spilts up into a large number of pairs of fission fragments with an average number of 2.5 neutrons. The reaction is accomplished with release of large amount of energy.

The average energy released per fission of uranium nucleus is of the order of 200 MeV.

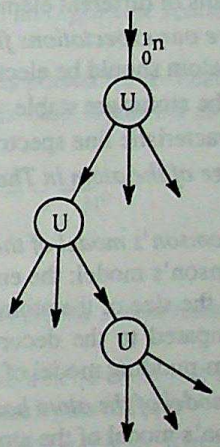
21. Chain reaction

The neutron released in a fission process can promote further fission and set up a self-sustained chain reaction. If the three neutrons, released due to fission of one atom of $^{235}_{92}U$, cause fission of three more atoms of $^{235}_{92}U$; and the process sustains itself as shown in figure below we have an uncontrolled chain reaction. This uncontrolled self-sustained reaction can result in explosive release of energy. This is the underlying principle of a fission bomb.

If, however, of the three neutrons produced, 2 are absorbed before thev can cause further fission, we have a controlled chain reaction. This is shown in part of the figure (b).



An uncontrolled chain reaction



A controlled chain reaction

A controlled chain reaction is the underlying principle of a nuclear reactor.

22. Nuclear reactor

A nuclear reactor makes use of a controlled chain reaction. The main constituents of a nuclear reactor are

(i) Fuel rods. These consists of enriched $^{235}_{92}U$.

(ii) *Control rods* : These rods are used to absorb, on the average, two of three neutrons produced due to fission of one atom of $^{235}_{92}U$; before they can cause further fission. *Cadmium* is frequently used for making control rods as it absorbs neutrons well.

(iii) *Moderator :* Moderator is used to *slow down* the fast neutrons produced due to fission of one atom of $^{235}_{92}U$. Heavy water or carbon graphite is commonly used as the moderator.

(iv) *Heat exchanger :* The energy released in nuclear fission is in the form of heat. Hot gases are circulated inside the reactor. These hot gases transfer their energy to external system in a heat exchanger.

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23. Nuclear fusion

Nuclear fusion is the phenomenon in which two light nuclei are fused together to form a single new nucleus. These reactions are also accompanied by the release of nuclear energy. To make nuclear fusion possible, the material has to be heated to very high temperature (~5000 to 6000 K). Nuclear fusion is also known as a thermonuclear reaction. In nuclear fusion four protons combine to form nucleus of helium atom. The possible reaction is represented as

$$_1^1H + _1^1H \rightarrow _1^2He + _{+1}^0e + Q_1$$

$$_1^2H + _1^1H \rightarrow _2^3He + Q_2$$

$$_2^3He + _2^3He \rightarrow _2^4He + 2\ _1^1H + Q_3$$

It is now believed that fusion process is primarily responsible for the release of energy by the Sun and stars. A nuclear fusion process is more energy efficient than a nuclear fission process.

The threat of a 'nuclear holocaust' is a serious threat to mankind. 'Nuclear radiations', have serious and significant biological consequences, and a nuclear bomb explosion can cause very serious damage and devastation. It is imperative, therefore, for all right thinking persons to do their utmost to dispel this serious threat.

SUBJECTIVE QUESTIONS ON UNIT – XI

Q.1. *In what respect do the atoms of different elements differ from each other ?* (1)

Ans. The atoms of different elements have (i) different mass number and (ii) different charge.

Q.2. *What are our expectations from a model of the atom ?* (2)

Ans. (i) The atom should be electrically neutral, as a whole.

(ii) Most of the atoms are stable

(iii) The characteristic line spectrum of the atom should be explainable in terms of the model of the atom.

Q.3. *Is the size of the atom in Thomson's model; the same as the atomic size in Rutherford's model ?* (1)

Ans. Yes

Q.4. *Why Thomson's model of the atom is known as a plum pudding model ?* (2)

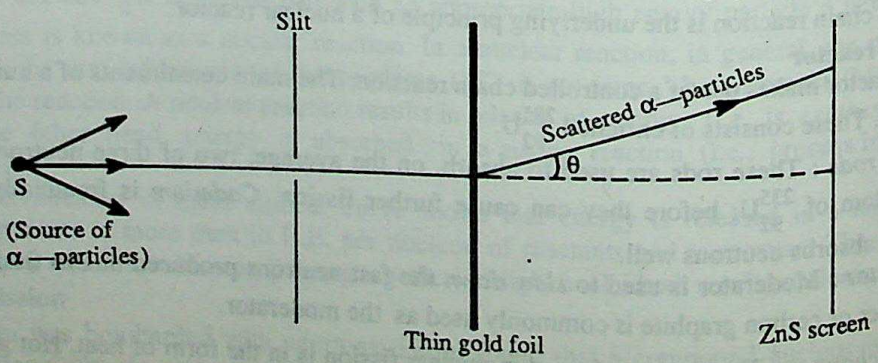
Ans. In Thomson's model; the entire mass and the positive charge is considered as distributed over a sphere of radius equal to the size of the atom. The negative electrons are arranged within the volume of the sphere. The electrons are compared to the decoration of plum over a pudding. Therefore, the Thomson's model is also known as the plum-pudding model of the atom.

Q.5. *Which model of the atom has a nearly continuous mass distribution in it ?* (1)

Ans. Thomson's model of the atom.

Q.6. *Draw a labelled diagram of Geiger--Marsden experiment on scattering of α- particles.* (1)

Ans.



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Q.7. *Describe the salient features of Geiger and Marsdon's experiment.* **(2)**

Ans. (i) Most of the α-parcticles undergo small angle scattering.

(ii) The number of α-particles scattered through an angle θ is;

(a) directly proportional to Z^2

(b) directly proportional to thickness t of foil.

(c) proportional to $1/\sin^4(\theta/2)$

(iii) Few α-particles undergo large angle seattering.

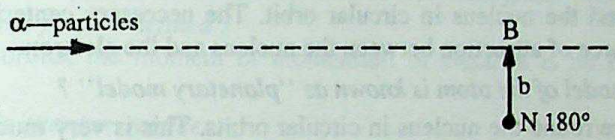
(iv) Very few of α-particles are almost turned back, i.e., are scattered through 180°.

Q.8. *Why was a very thin gold foil used in the α - particle scattering experiment ?* **(1)**

Ans. The foil of gold used is thin so that a large number of α-particles are able to pass through the foil.

Q.9. *What is meant by impact parameter ?* **(1)**

Ans. The impact parameter (b) is the minimum distance between the nucleus (N) and the α-particle, if α-particles had moved in a straight line as shown in figure without experiencing any force due to the nucleus.



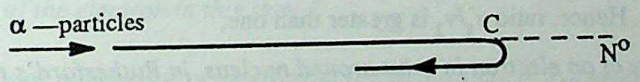
NB = the impact parameter.

Q.10. *What is the value of angle of the α particle scattering for zero impact parameter ?* **(1)**

Ans. 180°

Q.11. *What do you understand by the distance of closest approach in an α particle scattering experiment ?* **(1)**

Ans. Figure shows an α-particle moving in such a direction that it is poised for a "head-on" collision. The minimum distance (NC) between the nucleus and the α-particle, in this case is known as distance of closest approach.



Q.12. *Kinetic energy of incident alpha particle on gold foil in Rutherford's experiment is doubled. How distance of closest approach is altered ?* **(1)**

Ans. The distance of closest approach is inversely proportional to the kinetic energy of incident α-particles. When K.E. of incident α-particle is doubled, the distance of closest approach gets halved.

Q.13. *Why the mass of the nucleus does not enter into the formula for angle of scattering but its charge does?* **(2)**

Ans. The force exerted by the nucleus on α-particle is the electrostatic force. It depends on the charge of nucleus, the charge of the α-particle and distance between them. The force does not depend on the mass of the nucleus. Therefore, mass does not enter into the formula for angle of scattering.

Q.14. *Name the factors which determine the trajectory of the scattered α particles.* **(2)**

Ans. The trajectory of α-particles depend on :

(i) The charge on the nucleus

(ii) The charge on the α-particle.

(iii) The initial velocity of projection of the α-particles.

(iv) The impact parameter.

Q.15. *What are the results of the Geiger-Marsden's experiment on α particles ?* **(2)**

Ans. The main results of Geiger-Marsden experiment are :

(i) Size of the atom is about an Å.

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(ii) There is no continuous distribution of mass over the entire size of atom.

(iii) The mass and the positive charge of an atom are concentrated in a small central part of the atom. This is known as the atomic nucleus.

Q.16. *What is the size of an atom ?*

Ans. About 10^{-10} m (1)

Q.17. *What is the size of atomic nucleus ?*

Ans. About 10^{-15} m (1)

Q.18. *What is the ratio of size of atom and the size of the nucleus ?*

Ans. About 10^5 (1)

Q.19. *Describe the basic facts of Rutherford's atomic model.* (2)

Ans. In the Rutherford's model of the atom :

(i) The nucleus of the atom is regarded as stationary. It possesses almost the entire mass and the total positive charge that the atom has.

(ii) Electrons revolve round the nucleus in circular orbit. The necessary centeripetal force on electron is provided by the electrostatic force of attraction between the nucleus and the electron.

Q.20. *Why Rutherford's model of the atom is known as "planetary model" ?* (2)

Ans. The electrons revolve round the nucleus in circular orbits. This is very much similar to the motion of the planets around the sun. Because of this similarity the Rutherford's model is known as the planetary model of the atom.

Q.21. *On Rutherford's model, r_1 and v_1 denote the radius and the speed of an electron around the nucleus. If r_2 and v_2 are the corresponding values for another orbit and $r_2 > r_1$, what is the value of v_1/v_2? Give reason in support of your answer.* (2)

Ans. Let r and v denote the radius and the speed of the electron in an orbit in Rutherford's model.

Then rv^2 = constant. Therefore, $r_1 v_1^2 = r_2 v_2^2$

Given $r_2 > r_1$, $\therefore v_2 < v_1$. Hence, ratio v_1/v_2 is greater than one,

Q.22. *Is the total energy of an electron in orbit around nucleus, in Rutherford's model, positive negative or zero ?* (1)

Ans. Negative.

Q.23. *In Rutherford's model of the atom what is the ratio of the magnitude of the total energy and magnitude of potential energy of an electron in orbit ?* (1)

Ans. $\dfrac{|\text{Total energy}|}{|\text{Potential energy}|} = \dfrac{1}{2}$

Q.24. *What are the limitations of Rutherford's atomic model ?* **(3)**

Ans. (i) The electron revolving around the nucleus is a charged particle. It is experiencing centripetal acceleration. According to the laws of the e.m. theory; it must loose energy by emitting radiation. As electron loses energy, its speed increases and radius of orbit decreses. The electron, therefore, follows a spiral path as shown and crash lands into the nucleus. The time for this process is a few millisecond only ! In other words, the atom is unstable.

(ii) Since electron loses energy continuously, its spectrum should be a continuous spectrum. However, experiments show that the spectrum of an atom is a line spectra.

Q.25. *How do you justify the assumption that nucleus is at rest while treating the motion of an electron around it ?* (2)

Ans. Since mass of electron is very small as compared to mass of nucleus; the radius of orbit of nucleus about the centre of mass of system is very small. Therefore, we can regard the nucleus to be stationary to a very good degree of approximation.

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Q.26. *State the basic postulates of Bohr's theory.* **(C.B.S.E 1994, 1995) (2)**

Ans. *Bohr's first postulate :* The electron cannot move around nucleus in every possible orbit. It moves only in some special orbits known as stationary orbits. An electron in a special orbit does not lose energy. In other words an electron in a stationary orbit does not obey laws of e.m. theory. The moment of momentum of an electron in a stationary orbit is an integral multiple of $h/2\pi$, h is Planck's constant.

Angular momentum of electron = $\frac{nh}{2\pi}$, n = 1, 2, 3, ...

n is known as the principal quantum number.

Bohr's Second postulate: Whenever an electron jumps, from one permitted orbit to another permitted orbit, the energy difference between the two is emitted or absorbed as a quanta of energy. Expressed mathematically.

$$E_{n_2} - E_{n_1} = h\nu$$

Q.27. *What are stationary orbits ?* **(1)**

Ans. Stationary orbits are special orbits. An electron in a stationary orbit does not lose any energy. In other words, an electron in a stationary orbit does not obey laws of electromagnetic theory of radiation.

Q.28. *How are stationary orbits defined ?* **(1)**

Ans. For stationary orbits, the moment of momentum of electron is an integral multiple of $h/2\pi$, h is Planck's constant.

Q.29. *Define principle quantum number.* **(1)**

Ans. Angular moemtum of electron in n^{th} permitted orbit = $\frac{nh}{2\pi}$

n = 1, 2, 3 ..., n is the principal quantum number.

Q.30. *Do outer orbits have greater energy as compared to inner orbits ?* **(1)**

Ans. The total energy of outer orbit is greater than the total energy of inner orbit.

Q.31. *What is the energy of electron when it is at a very great distance from the nucleus ?* **(1)**

Ans. Zero

Q.32. *The total energy of an electron in the first excited state of the hydrogen atom is about –3.4 eV. What is the kinetic energy of the electron in this state ?* **(C.B.S.E, 1995)**

Ans. + 3.4 eV

Q.33. *What is the angular momentum of an electron in ground state in hydrogen atom ?* **(1)**

Ans. $h/2\pi$

Q.34. *What is the ratio of the radii of first two permitted orbits in hydrogen atom ? Give reasons in support of your answer.* **(2)**

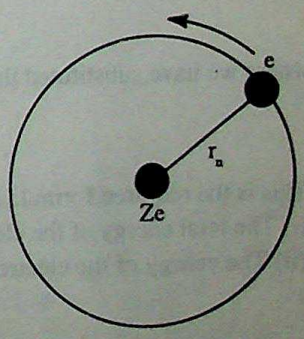
Ans. 4. The radius (r_n) of nth permitted orbit is proportional to n^2. Therefore,

$$\frac{r_2}{r_1} = \left(\frac{2}{1}\right)^2 = 4$$

Q.35. *What is total energy of an electron in ground state in hydrogen atom ?* **(1)**

Ans. – 13.62 V

Q.36. *State Bohr's postulates. Derive an expression for the energy of the atom in its nth stationary state in the hydrogen atom.* **(5)**



Ans. The basic postulates of Bohr's theory of the hydrogen atom are :

(i) The electron moves round the nucleus only in certain permitted orbits known as the stationary orbits. The electron does not lose any energy by emitting electromagnetic waves while moving in these orbits.

(ii) The permitted orbits are those in which the electron angular momentum is an integral multiple of $\frac{h}{2\pi}$.

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$$m v r = n \frac{h}{2\pi} \quad (n = 1, 2, 3, \ldots)$$

'n' is known as the principal quantum number of the orbit.

(iii) Whenever an electron 'jumps' from one stationary orbit to another it emits (absorbs) a quanta of radiation (a photon) whose energy is equal to the difference of the electron energies in the two orbits involved in the transition.

$$h\nu = E_{n_2} \sim E_{n_1}$$

The photon is absorbed when $n_2 > n_1$ and is emitted when $n_2 < n_1$.

Let us now derive an expression for the energy of the electron while orbiting in the nth permitted orbit. For an electron in a circular orbit of radius r_n; the centripetal force is equal to the force of attraction of the nucleus on the electron. Expressed mathematically; by the condition :

$$\frac{m v^2}{r_n} = \frac{1}{4\pi\varepsilon_o} \frac{Z e^2}{n h} \quad \ldots(i)$$

From Bohr's first postulate $m v_n r_n = \frac{h}{2\pi}$

Solving these two equations for v_n and r_n, we get

$$v_n = \frac{2\pi}{4\pi\varepsilon_o} \frac{Ze^2}{n h} = \frac{1}{4\pi\varepsilon_o} \frac{2\pi Z e^2}{h} \cdot \frac{1}{n} \quad \ldots(iii)$$

and

$$r_n = \frac{4\pi\varepsilon_o h^2}{4\pi^2 Ze^2 m} n^2 \quad \ldots(iv)$$

We next notice that the electron's energy is made up of two parts: kinetic energy and potential energy. We have

$$\text{K.E.} = \frac{1}{2} m v_n^2 = \frac{1}{2} \cdot \frac{1}{4\pi\varepsilon_o} \frac{Ze^2}{r_n} \quad \text{(from (i))} \quad \ldots(v)$$

and

$$\text{P.E.} = \int_{\infty}^{r_n} \frac{1}{4\pi\varepsilon_o} \frac{Ze^2}{r^2} dr$$

$$= -\frac{1}{4\pi\varepsilon_o} \cdot \frac{Ze^2}{r_n} \quad \ldots(vi)$$

$\therefore$ Total energy of the electron is the nth orbit is

$$E_n = \frac{1}{2} \cdot \frac{1}{4\pi\varepsilon_o} \frac{Ze^2}{r_n} + \left(-\frac{1}{4\pi\varepsilon_o} \cdot \frac{Ze^2}{r_n} \right)$$

$$= -\frac{1}{2} \cdot \frac{1}{4\pi\varepsilon_o} \cdot \frac{Ze^2}{r_n} = -\frac{2\pi^2 Z^2 e^4 m}{(4\pi\varepsilon_o)^2 n^2 h^2} \quad \ldots(vii)$$

where we have substituted the value of r_n from Eqn. (iv). Thus,

$$E_n = -\frac{2\pi^2 Z^2 e^4 m}{(4\pi\varepsilon_o)^2 h^2} \cdot \frac{1}{n^2}$$

This is the required formula and it shows that

(i) The total energy of the electron is negative, hence, it is a bound particle.

(ii) The energy of the electron increases as n increases. Thus, outer orbits have greater energy than the inner ones.

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(iii) The energy magnitude varies as $\frac{1}{n^2}$

Q.37. *Give the interpretation of negative sign in the energy expression of the electron in the hydrogen atom.* **(2)**

Ans. The potential energy of an electron in orbit is negative because electron is bound to the nucleus. Magnitude of K.E. is less than the magnitude of P.E. Therefore, total energy of electron, in any orbit, is negative. The –ve sign of total energy expression means that energy has to be given to electron in order to make it (electron) move away from the attractive pull of the nucleus.

Q.38. *What is Bohr's frequency condition in connection with emission and absorption of energy by an atom?* **(1)**

Ans. $E_{n_2} - E_{n_1} = h\nu$

Q.39. *What is energy in electron volt of a quanta of radiation emitted when an electron jumps from excited state to ground state in hydrogen atom ?* **(1)**

Ans. The first excited state is the second allowed state. The ground state is the first allowed state. Also

$$E_1 = -13.6 \text{ eV};$$

$$E_2 = -\frac{13.6}{(2)^2} = -3.4 \text{ eV},$$

$\therefore$ Energy of quanta emitted when electron jumps from first excited state to ground state $= E_2 - E_1$

$$= -3.4 - (-13.6) \text{ eV} = 10.2 \text{ eV},$$

Q.40. *Explain how Bohr's theory accounts for the observed spectrum of hydrogen atom ?* **(3)**

Ans. To explain the observed spectrum of hydrogen atom, we note that energy E_n of electron in n^{th} orbit is

$$E_n = -\frac{2\pi^2 Z^2 e^4 m}{(4\pi\varepsilon_o)^2 h^2}\frac{1}{n^2} \quad \text{... (i)}$$

We can now get the general formula for the *wave numbers* of the hydrogen spectral lines. We have, for a transition from $n = n_2$ orbit to the $n = n_1$ orbit,

$$h\nu = E_{n_2} - E_{n_1} = \frac{2\pi^2 Z^2 e^4 m}{(4\pi\varepsilon_o)^2 h^2}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

$\therefore$

$$\nu = \frac{2\pi^2 Z^2 e^4 m}{(4\pi\varepsilon_o)^2 h^3}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) \quad \text{...(ii)}$$

Now wave number $(= \bar{\nu})$, being equal to $\frac{1}{\lambda}$, is given by $\bar{\nu} = \frac{\nu}{c}$

$$\therefore \bar{\nu} = \frac{2\pi^2 Z^2 e^4 m}{(4\pi\varepsilon_o)^2 ch^3}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

$$= RZ^2\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) \quad \text{...(iii)}$$

where

$$R = \frac{2\pi^2 e^4 m}{(4\pi\varepsilon_o)^2 ch^3} \quad \text{...(iv)}$$

R is known as the Rydberg constant.

Eqn. (iii) represents the general formula for the hydrogen spectral lines as per the *Bohr's theory.*

(i) *Lyman series :* This arises from transitions from higher orbits to the n = 1 orbit. Its general formula is

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$$\bar{\nu}_L = R Z^2 \left(\frac{1}{1^2} - \frac{1}{n^2}\right); \quad n = 2, 3, 4...$$

(ii) *Balmer series :* This arises from transitions from higher orbits to the n = 2 orbit. Its general formula is

$$\bar{\nu}_B = R Z^2 \left(\frac{1}{2^2} - \frac{1}{n^2}\right); \quad n = 3, 4, 5...$$

(iii) *Paschen series :* This arises from transition from the higher orbits to the n = 3 orbit. Its general formula

$$\bar{\nu}_P = R Z^2 \left(\frac{1}{3^2} - \frac{1}{n^2}\right); \quad n = 4, 5, 6, 7...$$

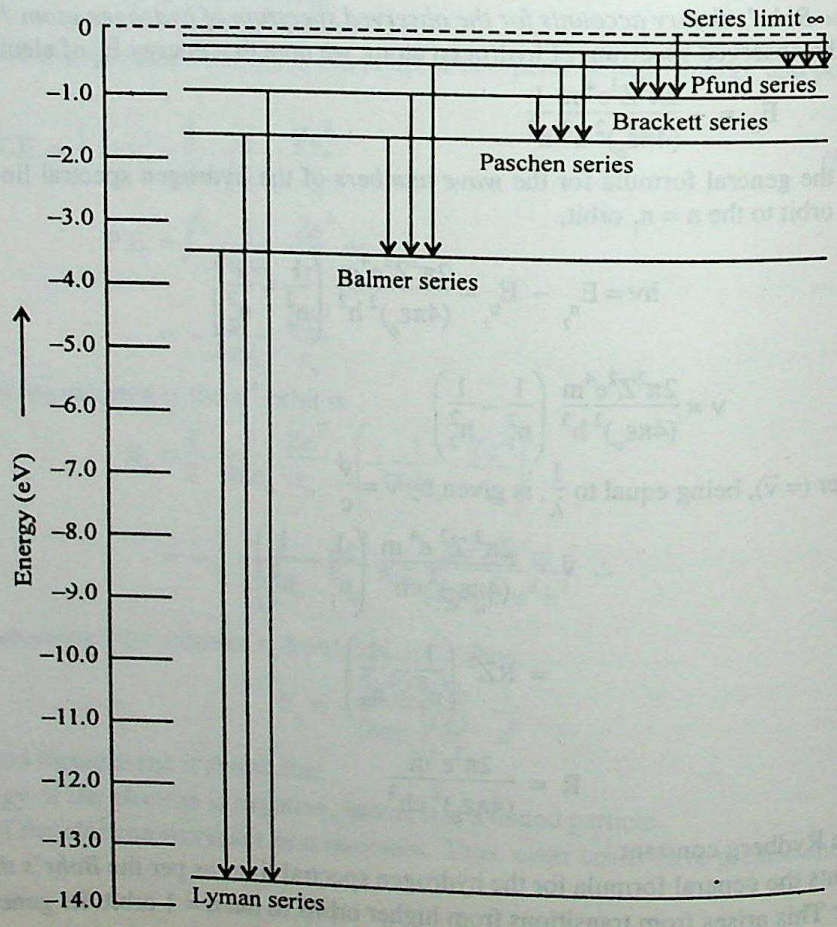
(iv) *Brackett series :* This arises from transitions from the higher orbits to the n=4 orbit. Its general formula

$$\bar{\nu}_{Br} = RZ^2 \left(\frac{1}{4^2} - \frac{1}{n^2}\right); \quad n = 5, 6, 7...$$

(v) *Pfund series :* This arises from transitions from the higher orbits to the n = 5 orbit. Its general formula is

$$\nu_{pf} = RZ^2 \left(\frac{1}{5^2} - \frac{1}{n^2}\right); \quad n = 6, 7, 8..$$

All these series have been shown on the energy level diagram in the fig. below.



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Q.41. *What is an empirical formula ?* **(1)**

Ans. A formula obtained on the basis of experimental observations is known as an empirical formula.

Q.42. *State Balmer's empirical formula* **(1)**

Ans. According to Balmer's formula, the wave number $\bar{\nu} = \frac{1}{\lambda}$ is $\bar{\nu} = R\left[\frac{1}{(2)^2} - \frac{1}{(n)^2}\right]$; $n = 3, 4, 5, 6...$

R is Rydberg's constant.

Q.43. *What is Bohr's raduis ?* **(1)**

Ans. The radius of the first permitted orbit of electron in hydrogen atom is known as Bohr's radius.

Q.44. *What is Rydberg's constant ?* **(1)**

Ans. $R = \left(\frac{1}{4\pi\varepsilon_o}\right)^2 \frac{2\pi^2 m Z^2 e^4}{ch^3}$

Q.45. *What are the dimensions of Rydberg's constant ?* **(1)**

Ans. $M^o L^{-1} T^o$

Q.46. *What is the value of Rydberg's constant for hydrogen ?* **(1)**

Ans. $1.099 \times 10^7\ m^{-1}$

Q.47. *With increasing quantum number, the energy difference between adjacent energy levels increases or decreases ?* **(1)**

Ans. Decreases

Q.48. *Explain why the spectrum of hydrogen atom has many lines although a hydrogen atom contains only one electron ?* **(2)**

Ans. One atom of hydrogen has one electron. When hydrogen atom is excited, this electron can jump to any of the permitted energy state depending upon value of excitation energy. In one atom when the excited electron returns to ground state one line is produced. In a finite mass of hydrogen, there are billions and billlions of atoms. Electrons in different atoms are excited to different energy states. When these electrons return to ground state different lines are produced.

Q.49. *Which series of hydrogen spectra lie in the infrared region ?* **(1)**

Ans. Paschen series

Q.50. *In which series of hydrogen spectra, the transitions involve the largest changes of energy ?* **(1)**

Ans. Lyman series

Q.51. *Name the series of hydrogen spectrum lying in the ultraviolet region.* **(C.B.S.E. 1995 Comptt.) (1)**

Ans. Lyman series

Q.52. *Name the series of the hydrogen spectrum which has least wavelength.* **(C.B.S.E. 1995 Comptt.) (1)**

Ans. Lyman series

Q.53. *What do you understand by the term the short wavelength limit of a series ?* **(1)**

Ans. The wavelength corresponding to the most energetic transition in a series gives the short wave length limit of the series.

Q.54. *What do you understand by the term the long wave length limit'' of a series ?* **(1)**

Ans. The wavelength corresponding to the least energetic transition in a series gives the long wave length limit of the series.

Q.55. *What are ''energy level diagrams'' What is their significance ?* **(2)**

Ans. The energy level diagram of an atom is a diagram in which each permitted energy state is indicated by a horizontal straight line on a chosen scale. On the left hand corner of the line the principle quantum number (n) is written. On the right hand corner the energy (E_n) of the state is written. On some conveniently chosen scale the separation between any two energy level represents the energy difference of the states.

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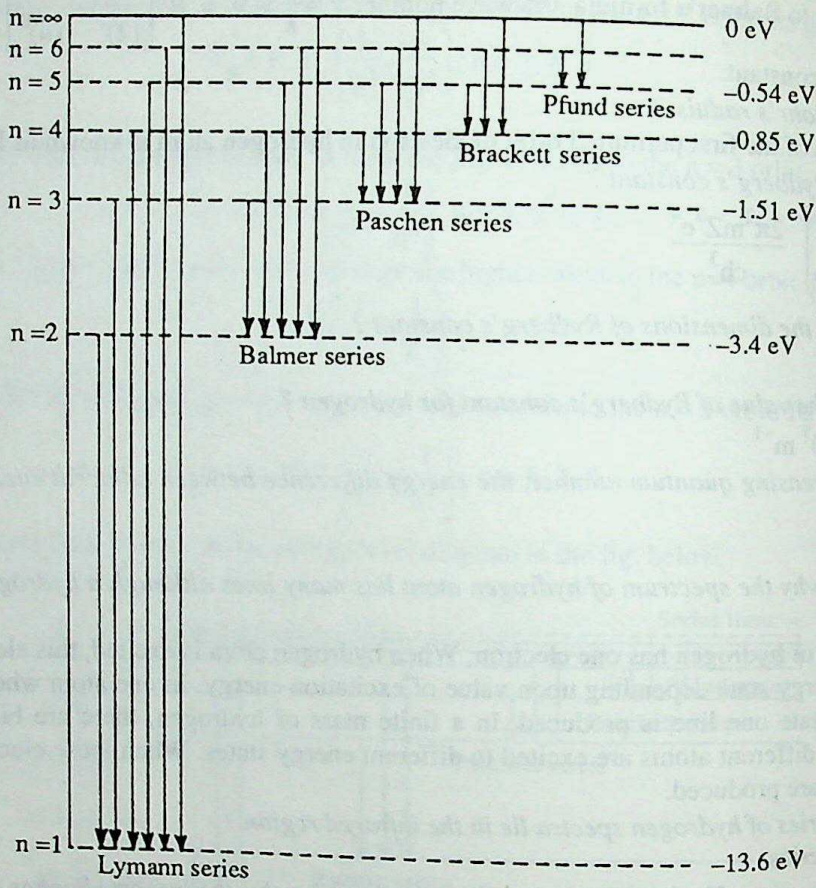
In terms of energy level diagram we can easily visualise the transitions responsible for a particular line in the spectrum of the atom. The energy of photon emitted is also easily obtained from the energy level diagram.

Q.56. *Indicate the various series of hydrogen spectra on a "energy level diagram".*

Ans.



Q.57. *Identify the series whose wave number is given by the relation*

$$\bar{\nu} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right);\ n = 4,\ 5,\ 6,\ 7$$

Ans. Paschen series

Q.58. *What is minimum wavelength of Lyman series ?*

Ans. For Lyman series

$$\bar{\nu} = \frac{1}{\lambda} = R\left[\frac{1}{(1)^2} - \frac{1}{(n)^2}\right];\ n = 2, 3, 4...$$

For minimum wavelength $n = \infty$. Therefore,

$$\frac{1}{\lambda_{min}} = R\left[\frac{1}{(1)^2} - \frac{1}{(\infty)^2}\right] = R$$

or

$$\lambda_{min} = \frac{1}{R}$$

Q.59. *What is H_α line in the hydrogen spectrun ?*

Ans. The H_α - line in hydrogen spectrum corresponds to a transition from $n = 3$ to $n = 2$ state.

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Q.60. *What are the limitations of Bohr's theory ? Can Bohr's theory suceessfully explain the spectra of alkali metals ?* **(2)**

Ans. (i) The wavelength of hydrogen like atom; (for example, singly ionised helium atom) are not exactly same as predicted by Bohr's theory. (ii) The "fine structure" and the "hyper fine structure" of spectral lines cannot be explained in terms of Bohr's theory.

Q.61. *What do you understand by the ''fine structure'' of spectral lines* **(1)**

Ans. According to Bohr's theory the spectral line should be a geometrically sharp line. We can also say that transitions corresponding to a particular line should be mono-energetic. However, careful experimental observations show that spectral lines are not geometrically sharp lines. Lines, having wave length on either side of the line, predicted by Bohr's theory are observed. This is known as the fine structure of spectral lines.

Q.62. *Does Bohr's theory explain the fine structure of spectral lines in the hydrogen spectrum ?* **(1)**

Ans. No. Bohr's theory cannot explain the fine structure of spectral lines.

Q.63. *What is the whole number rule ?* **(1)**

Ans. The masses of different atoms are very nearly integral multiples of the mass of hydrogen atom. This is known as the whole number rule.

Q.64. *What are isotopes ?* **(1)**

Ans. Isotopes are atoms of same element identical in all other aspect except their mass.

Q.65. *We know that the atomic mass of an element is the weighted average of the atomic masses of different isotopes of that element. This explain why atomic masses of many elements show large deparature from integer values. However, even if we consider masses of individual isotopes they are not strictly integer multiples of a hydrogen atom. How can we account for this fact ?* **(2)**

Ans. We know that the nucleus of the atom consists of protons and neutrons. In isotopes of same element the number of neutrons is different. When an atom is formed from its constituent nucleons (i.e., protons and neutrons) a part of mass of nucleons is converted into energy. This is the binding energy of the nucleus. Since the binding energy of different isotopes of the same atom is different; the mass of an isotope is not an exact, integral multiple of mass of hydrogen atom.

Q.66. *What are isotopes ? How did their discovery support the whole number rule'' due to Prout ?* **(2)**

Ans. Isotopes are atoms of the same element identical in all other respects, except their mass. After the discovery of isotopes; it was postulated that the (chemical) atomic weight of an atom is the weighted mean of the masses of different isotopes. Though atomic weight is not a whole number, the masses of isotopes are nearly integral multiples of mass of hydrogen. This is Prout's "whole number rule".

Q.67. *What is a mass spectrograph ?* **(1)**

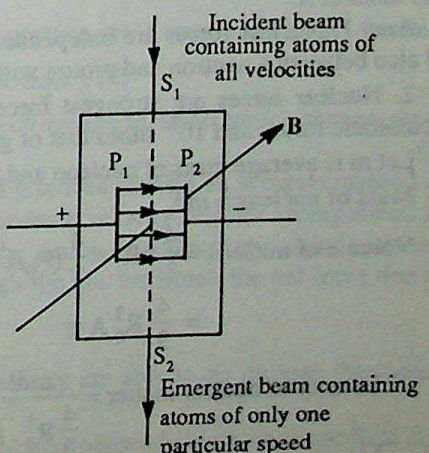
Ans. A mass spectrograph is an instrument used to determine masses of various atoms.

Q.68. *What is a velocity selector ?* **(1)**

Ans. A velocity selector is an appropriate arrangement of electric and magnetic fields. When a beam of atoms, having different velocities, enter in this region, only atoms of a particular speed continue moving straight. This beam emerging out straight, therefore, contains atoms of one speed only.

Q.69. *Explain the working of a velocity selector.* **(2)**

Ans. Figure below shows the arrangement of a velocity selector. S_1 and S_2 are slits having very fine openings. P_1 and P_2 are plate of a parallel capacitor between which an electric field **E** is established. The magnetic field **B** is applied in a direction perpendicular to that of **E** and the direction of motion of atoms. Directions of **E** and **B** are so adjusted that the direction of force, due to them, on charged atoms, are in opposite direction. For the atoms emerging out straight, the net force is zero. In other words; force due to **E** and **B** are equal in magnitude and opposite in direction. If v is speed of these atoms, then



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$qE = Bqv$ or $v = \frac{E}{B}$

Q.70. *Explain how we achieve a linear mass scale in Bainbridge's mass spectrograph.*

Ans. In a Bainbridge's mass spectrometer the atoms of a particular speed (v) move in a perpendi magnetic field **B.** Let R be be radius of circular path of atoms of mass m.

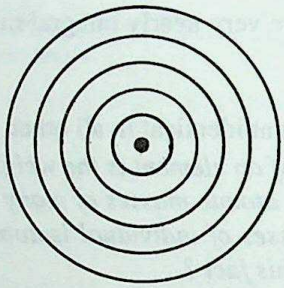
Then $\frac{mv^2}{R} = Bqv$ or $R = \frac{mv}{Bq}$

Since, B, q and v are same for all atoms $R \propto m$. We, thus, have a linear mass scale.

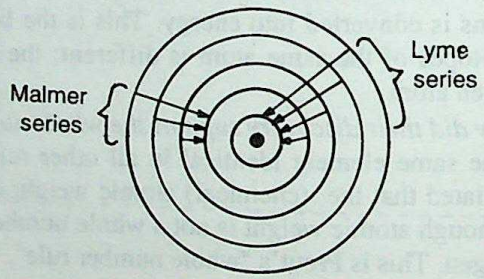
Q.71. *What is the advantage of having a linear mass scale in Bainbridge's mass spectrograph ?*

Ans. The masses of different atoms can be easily compared with one another.

Q.72. *In the diagram given below for the stationary orbits of the hydrogen atom, make the trans representing the Balmer and Lyman series.*



Ans. **(CBSE 1998)**



Q.73. *State two properties of nuclear forces. Prove that the density of matter in nuclei is independe mass number A.* **(CBSE 1997 Compt.)**

Ans. 1. Nuclear forces are independent of charge. These acts between a pair of neutrons, a pair of pro and also between a neutron and proton with the ame strength.

2. Nuclear forces are strongest forces in nature. The magnitude of nuclear forces is 100 times tha electrostatic forces and 10^{38} times that of gravitational forces.

Let m is average mass of nucleon and R is the nuclear radius and A the mass number of element. Then,

Mass of nucleus = mA

Volume of nucleus $= \frac{4}{3}\pi R^3 = \frac{4}{3}(R_0 A^{1/3})^3 \pi \quad (\because R = R_0 A^{1/3})$

$= \frac{4}{3} R_0^3 A \pi$

$\therefore$ Density of nuclear matter $= \frac{mA}{\frac{4}{3} R_0^3 . A} \pi = \frac{3m}{4R_0^{\ 3} \pi}$

which is independent of A.

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Q.74. *State Bohr's postulates. Using these postulates derive an expression for the total energy of an electron in nth orbit of an atom. What does negative value of this energy signify?* **(CBSE 1997) (5)**

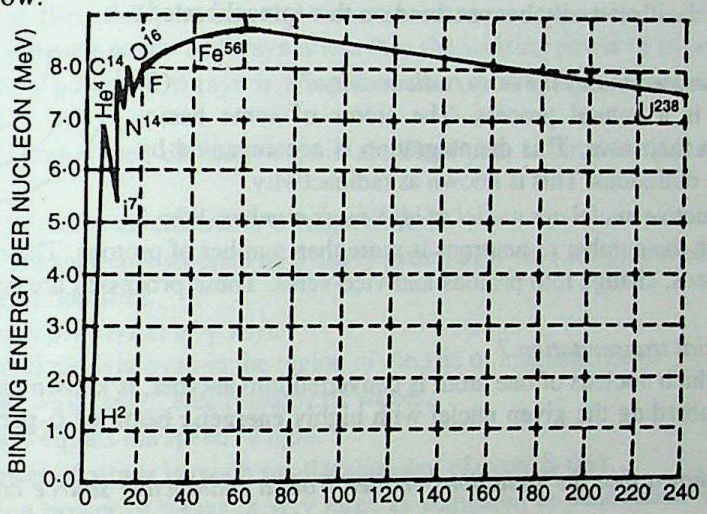
Ans. See answer to question no 36.

Q.75. *By using Bohr's postulates for atomic model, derive mathematical expression for (i) kinetic energy (ii) potential energy of an electron revolving in an orbit of radius r. How does the potential energy change with increase in the principal quantum number (n) for the electron and why?* **(CBSE 1998) (5)**

Ans. See answer to question no. 36.

Q.76. *Draw a graph showing the variation of binding energy per nucleon with the mass number of different nuclei. State two inferences from the graph.* **(CBSE 2000) (2)**

Ans. The graph between the binding energy per nucleon and the mass number A is called binding energy curve which is shown below.



The inferences drawn from the graph are

(i) The binding energy per nucleon is very low for light nuclei such as deuterium ($_1H^2$), helium ($_2He^4$) etc.

(ii) The binding energy per nucleon rises rapidly with increasing value of A upto A = 20.

Q.77. *You are given two nuclei $_3X^7$ and $_3Y^4$. Are they isotopes of the same element? State with reason, which one of the two nuclei is likely to be more stable?* **(CBSE 2000) (2)**

Ans. Yes, they are isotopes of same nuclei.

The isotope $_3X^7$ has 3 protons and 4 neutrons while $_3Y^4$ has 3 protons are 1 neutron. So $_3X^7$ has less proton - proton repulsion as compared to $_3Y^4$. Hence, $_3X^7$ is more stable than $_3Y^4$.

Q.78. *Explain briefly the basic details of the Bainbridge's mass spectrograph for determining the masses of the isotopes of a given element?* **(3)**

Ans. The Bainbridge mass spectrograph is shown in the figure and provides us with an accurate method of determining the (relative) masses of ions of a given velocity. It incorporates a velocity selector arrangement. In this arrangement, the incoming collimated ion beam is subjected to the action of (oppositely acting) crossed electric and magnetic fields. Only those ions are then able to go through the slit for which the net force due to the two fields becomes zero. This happens when

$$qE = qvB \quad \text{or} \quad v = E/B$$

Thus, for given electric and magnetic fields, only ions of given velocity are able to go through the 'beam limiting slit.'

The ions of this (known) velocity are then subjected to action of another (perpendicular) magnetic field B_1. Their trajectory is then bent into an arc of a circle whose radius R is given by

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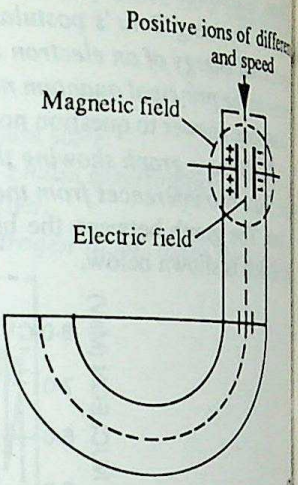
$$\frac{mv^2}{R} = qvB_1 \text{ or } R = \frac{mv}{qB_1}$$

Since v is constant for these ions (of a given charge q), we may write R = km where $k = \frac{v}{qB_1}$



The radii of the arcs, into which the ions are bent, are; thus; proportional to their respective masses. From the figure it is then clear that the distance of the 'spot' (on a photographic plate), from the centre of the limiting slit, for ions of a given mass m is proportional to m. We, thus, get a linear mass scale which can easily be calibrated using some ions of known masses. The masses of other isotopes can then easily be measured on this (precalibrated) linear mass scale.

Q.79. *What do you understand by the term radioactivity ?* **(1)**

Ans. Radioactivity is a natural process. The atoms of some heavy elements disintegrate, on their own. This disintegration is accompanied by the emission of energetic radiations. This is known as radioactivity.

Q.80. *Natural radioactive nuclei are nuclei of high mass number. Why ?*

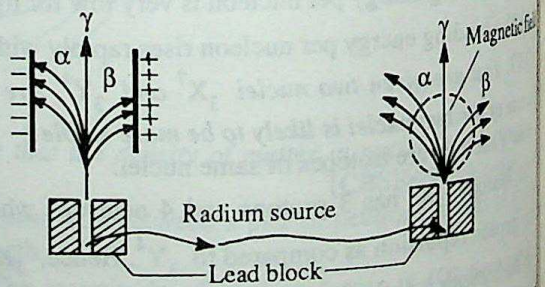
Ans. In heavy nuclei; the number of neutrons is more than number of protons. The nucleus is unstable. A neutrons, inside the nucleus, change into protons and vice-versa. These processes are accompanied by emiss of radiations.

Q.81. *What is artificial transmutation ?*

Ans. A process in which nucleus of one atom is converted into another, is known as artificial transmutati This is achieved by bombarding the given nuclei with highly energetic beam of α-particles, neutrons, proto etc.

Q.82. *How was it shown that the radiations emitted from a radioactive source consists of three differ components ?*

Ans. The required experiment was done by Rutherford and his co-workers using a simple set up of the type shown in the fig. A sample of a radioactive element like radium, was placed at the bottom of a thin hole drilled in a block of lead. The resulting collimated beam of radioactive radiations, coming out of the hole opening, was subjected to the action of an electric or a magnetic field in successive observations. It was found that in each case the beam splits up into three components; (i) a positively charged component that was named α-rays, (ii) a negatively charged component that was named as β-rays and (iii) an electricity neutral component that named as γ-rays. It was, thus, established that the radioactive radiations are made up of three distinct components.



Q.83. *What are the important properties of α rays ?*

Ans. The following are the important properties of α-rays:

(i) α-rays are positively charged particles. e/m of α-particles is same as that of a doubly ionised he atom. In other words, an α-particle is nothing but the nucleus of a helium atom. It is represented as $_2^4He$.

(ii) α-rays have a high ionisation power. An α-particle produces about 105 ion pairs per cm.

(iii) α-rays are easily absorbed by matter (i.e., penetration power of α-rays is small). A 0.1 cm th aluminium foil can absorb an α-particle.

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(iv) α-particles can cause ionisation in air, up to certain distance, known as the range of α-particles. If α-particles travel a distance more than, their range, they are no longer able to ionize air. In other words, α-particles have a will defined range (R). The range (R) is related to the speed (v) of α-particle by the relation $R = kv^3$, where *k* is a constant

(v) α-rays can cause fluorescence in materials like zinc sulphide.

(vi) a-particles undergo scattering while passing through thin metal sheets.

(vii) α-rays effect a photo film.

(viii) α-particles are used as bullets to produce artificial disintegration of an atom.

Q.84. *List important properties of β rays?* **(2)**

Ans. (i) (i) β-rays are negatively charged particles. The "specific charge" of β-ray particle is same as that of fast moving electrons. In other words, β-rays are nothing but a beam of fast moving electrons.

(ii) The energy of β-particle, having the same speed as an α-particle, is less than the energy of the α-particle. Therefore, ionising power of β-rays is less than the ionising power of α-rays.

(iii) The penetration power of β-rays is more than that of α-rays. An aluminium foil about 0.5 cm thick absorbs β-particles.

(iv) β-rays donot show a well defined range in air. Their path in air is irregular unlike α-rays which travel straight in air.

(v) β-rays are deflected by an electric or a magnetic field.

(vi) When β-rays are suddenly stopped by a heavy material, X-rays are produced,

(vii) β-rays effect a photofilm.

Q.85. *List important properties of γ rays.* **(2)**

Ans. (i) γ-rays travel straight even in the region of electric or magnetic fields.

(ii) γ-rays are short wavelength electromagnetic waves,

(iii) Speed of γ-rays equals the speed of light.

(iv) Ionisation power of γ-rays is much smaller than that of even β-rays.

(v) The penetration power of γ-rays is very large as compared to penetration power of β-rays. γ-rays are able to penetrate a concrete wall a few cm thick.

(vi) The intensity (I) of γ-rays after travelling a distance (x) in a material is $I = I_o\ e^{-\mu x}$

where I_o is intensity of incident γ-rays. μ is a constant for a material and is known as the absorption coefficient.

(vii) γ-rays can produce fluorescence.

(viii) γ-rays can effect a photofilm.

Q.86. *What do you understand by the term "scintillations" ?* **(1)**

Ans. When the α-rays emitted by a radioactive source are allowed to fall on a fluorescent screen (say, by coating zinc sulphide over a thin glass disc), they produce distinct tiny flashers of light on the screen. We do not get a uniform continuous emission of light from the fluorescent screen but only successive flashes that can be counted. These distinct (countable) flashes are referred to as scintillations. There appearance shows that a beam of α-rays consists of distinct particles that hit the screen 'one by one'. Each scintillation corresponds to the arrival of one α-particle on the screen. We can, therefore, count these scintillations and take them as a measure of the number of α-particles hitting the screen.

Q.87. *How will you define the range of α particle ?* **(1)**

Ans. In a given medium, α-particles lose their ionising power, rather abruptly, after travelling a definite distance. This distance is known as the range of α-particles.

Q.88. *State Geiger's law.* **(1)**

Ans. According to Geiger's law $R \propto v^3$ where R is range of α-particles and v is the speed of α-particles.

Q.89. *What are the basic features of Rutherford's Soddy theory ?* **(2)**

Ans. According to the Rutherford-Soddy theory:

(i) A given radioactive nucleus decays by the emission of either an α-particle or a β-particle but not both simultaneously. We, thus, have radioactive nuclei that are α-emitters and other that are β-emitters.

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(ii) γ-rays can accompany the emission of either α-rays or β-rays.

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(iii) When a radioactive nucleus emits an α-particle, its mass number goes down by 4 units and its atomic number by 2 units.

$$^{A}_{Z}X \rightarrow \, ^{A-4}_{Z-2}Y \; ^{4}_{2}He$$

(iv) When a radioactive nucleus decays by emission of a negative β-particle (an electron), its mass number remains unchanged but its atomic number goes up by one unit :

$$^{A}_{Z}X \rightarrow \, ^{A}_{Z+1}Y + \, ^{0}_{-1}e$$

(v) When a radioactive nucleus decays by the emission of a positive β-particle (a positron), its mass number remains unchanged but its atomic number goes down by one unit:

$$^{A}_{Z}X \rightarrow \, ^{A}_{Z-1}Y \; ^{0}_{+1}e$$

Q.90. *Name four different radioactive series.* (1)

Ans. (i) Uranium series (ii) Actinium series (iii) Thorium series (iv) Neptunium series.

Q.91. *All the naturally occurring radioactive series terminate at lead as their final product. Explain why ?* (2)

Ans. When a (parent) radioactive element decays either by an α or a β emission; it forms a daughter element which, in general, is again radioactive. This (daughter) element, therefore again decays to form the next daughter element. This sequence of parent-daughter decays will obviously continue till a non-radioactive or stable element is reached. It turns out that this stable element in all the three naturally occurring radioactive series is an isotope of lead. It is for this reason that the final product of all the three series is (an isotope of) lead.

Q.92. *A radioactive element is dissolved in a liquid and the solution heated. Will the activity of the solution be same as that of the element ?* (1)

Ans. The activity of solution remains unchanged.

Q.93. *Define the term decay constant for a radioactive substance. What is the relation between decay constant and half-life period ?* **[C.B.S.E. 1993]**

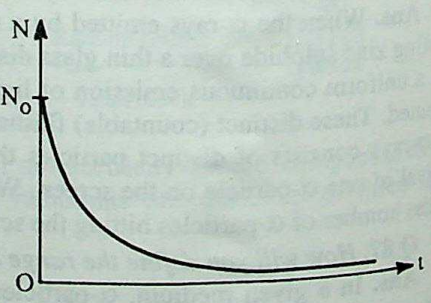
Ans. The decay constant (λ) of a radioactive material is the rate of disintegration per unit number of radioactive atoms present.

Expressed mathematically, $\lambda = \dfrac{\left|\dfrac{dN}{dt}\right|}{N}$

Also, $T_{1/2} = \dfrac{0.693}{\lambda}$

Q.94. *Give an account of the law of disintegration of the radioactive substances.* (3)

Ans. Let us start with N_o number of atoms of a radioactive element. Let N be the number of its atoms left after a time t.



Let $\dfrac{dN}{dt}$ be the rate of disintegration at this stage. On the basis of laws of statistics, we then have,

$$\frac{dN}{dt} \propto N \text{ or } \frac{dN}{dt} = -\lambda N \qquad ...(i)$$

where λ is a constant of proportionality. It is a constant for a particular material. It is known as the disintegration constant. The -ve sign in eqn. (i) indicates that N decreases as time increases. We can rewrite Eqn. (i) as

$$\frac{dN}{N} = -\lambda \, dt \qquad ...(ii)$$

Integrate eqn (ii)

$$\int_{N=N_o}^{N=N} \frac{dN}{N} = -\lambda \int_o^t dt \quad \text{or} \quad l_n\left(\frac{N}{N_o}\right) = -\lambda t$$

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$$N = N_0 e^{-\lambda t}$$ ...(iii)

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or

The figure gives variation of N with time t. Eqn. (iii) is exponential law of radioactive disintegration.

Q.95. *State the law of radioactive transformation. Obtain expression for half life and mean life.*

Ans. Let N_0 and N denote the number of radioactive atoms present at t = 0 and t = t respectively. According to law of radioactive disintegration

$$N = N_0 e^{-\lambda t} \quad ...(i)$$

(i) *Half-life* ($T_{1/2}$) of a radioactive material is the time in which the number of radioactive atoms reduces to half of what it is at the beginning of this time interval. Expressed mathematically;

$$N = \frac{N_0}{2} \text{ at } t = T_{1/2}$$

From eqn (i) $\frac{N_0}{2} = N_0 e^{-\lambda T_{1/2}} \Rightarrow \frac{1}{2} = e^{-\lambda T_{1/2}}$

or $e^{\lambda T_{1/2}} = 2$ or $\lambda T_{1/2} = l\text{n } 2$

$$\therefore \quad T_{1/2} = \frac{l\text{n } 2}{\lambda} = \frac{0.693}{\lambda} \quad ...(ii)$$

(ii) *Mean life* (τ) is $\tau = \dfrac{\text{Sum total of lives of all radioactive atoms}}{\text{Total number of radioactive atoms}}$

Let N and N+dN be the number of radioactive atoms present at time t = t and t = t + dt. The sum total of the lives of dN atoms = $t\,|dN| = t\lambda N_0 e^{-\lambda t}\,dt$

$$\therefore \text{ Sum total of lives of all radioactive atoms } = \int_{t=0}^{t=\infty} t\,|dN|$$

$$= N_0 \times \int_0^\infty t\, e^{-\lambda t}\,dt$$

$$= N_0 \lambda \left[\left(\frac{t\, e^{-\lambda t}}{(-\lambda)} \right)_0^\infty \int_0^\infty \frac{e^{-\lambda t}}{(-\lambda)} \cdot 1\,dt \right]$$

$$= N_0 \left(\frac{\lambda}{\lambda} \right) \int_0^\infty e^{-\lambda t}\,dt = N_0 \left[\frac{e^{-\lambda t}}{-\lambda} \right]_0^\infty = \frac{N_0}{\lambda}$$

$$\text{Mean life} = \tau = \frac{(N_0/\lambda)}{N_0} = \frac{1}{\lambda}$$

Q.96. *Define half-life of the radioactive material establish its relation with decay constant.*

(C. B.S.E. 1995) (2)

Ans. The half-life ($T_{1/2}$) of a radioactive material is the time in which the number of radioactive elements become half of what it is at the beginning of the time interval.

Refer to answer No. 94.

Q.97. *How will you define the mean life of a radio active element?* **(1)**

Ans. The mean life (τ) of a radioactive atom is the ratio of the sum total of the lives of all radioactive elements to the total number of radioactive elements.

Q.98. *The radioactivity of the sample is A_1 at time t_1 and A_2 at a time t_2. The mean life of specimen is τ. What is the number of atoms that have disintegrated in the time interval $(t_2 - t_1)$?* **(1)**

Ans. Let N_1 and N_2 be number of radioactive elements present at time t_1 and t_2 respectively.

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Then $A_1 = \left|\frac{dN_1}{dt}\right| = \lambda N_1$ and $A_2 = \left|\frac{dN_2}{dt}\right| = \lambda N_2$

$$\therefore \quad (A_1 - A_2) = \lambda\ [N_1 - N_2] \quad \text{or} \quad N_1 - N_2 = \frac{(A_1 - A_2)}{\lambda}$$

Obviously $(N_1 - N_2)$ is the number of radioactive atoms that have disintegrated in the time interval $(t_1 - t_2)$.

Q.99. *Define a curie.* (1)

Ans. 1 curie $= 3.7 \times 10^{10}$ disintegrations per second.

Q.100. *Can we estimate the age of the earth from the studies of radioactivity ? Explain.* (2)

Ans. Yes. We determine the relative ratio of the amount of (the stable isotope of) lead and uranium present in a given sample of a uranium containing rock. We assume that this lead has been formed only through the successive disintegrations of uranium, knowing the sequence of a elements formed in the uranium series, and the half life of each of them, we then use this information to calculate the time in which we will get the observed percentage of lead in the given sample believed to be containing only uranium at the time of its formation. We take this time to be an estimate of the *age* of the given sample and, therefore, of the earth itself.

Q.101. *Name two radioactive elements which are not found in observable quantities in nature. Why is it so?* **[C.B.S.E.,1995 Comptt.]**

Ans. Actinium and Neptunium.

The half-life of these two elements is comparatively small.

Q.102. *The β decay of a free proton is not possible but of a proton bound in the nucleus is possible. Is this statement true ?* (1)

Ans. Yes

Q.103. *What do you understand by artificial radioactivity?* (2)

Ans. Artifical radioactivity is the phenomenon of radioactivity, shown by isotopes obtained through nuclear reactions in the laboratory.

Q.104. *What is nature of β–rays emitted in artificial radioactivity ?* (2)

Ans. β-rays emitted in artificial radioactivity, quite often, consist of *positrons.*

Q.105. *Define mass number of a nucleus.* (1)

Ans. The mass number (A) of a nucleus is the sum of the number of protons and neutrons making the nucleus.

Q.106. *Define atomic number of a nucleus.* (1)

Ans. The atomic number (Z) of a nucleus equals the number of protons inside the nucleus.

Q.107. *Are electrons present inside the nucleus ?* (1)

Ans. No

Q.108. *Explain why electrons cannot be present in a nucleus ?* (3)

Ans. (i) If electrons are present inside the nucleus the nuclear magnetic moment must be of the order of the magnetic moment of electrons. However, experiments show that nuclear magnetic moment is much smaller than the magnetic moment of electron.

(ii) If one calculates the "*nuclear spin*" on the basis of "electron-proton" hypothesis, the nuclei predicted to have "*even-spin*" shows properties same as that of a nucleus having "odd-spin" and vice-versa.

(iii) According to the Heisenberg's uncertainity principle of electron, is confined within a nucleus the uncertainity in its position $\Delta x \sim 10^{-15}$ m. The uncertainity in the energy of electron is than much more than the binding energy of the nucleus.

Q.109. *Who discovered neutrons ?* (1)

Ans. Chadwick

Q.110. *Discuss the evidence that led to the discovery of the neutrons.* (3)

Ans. Bothe & Becker, in 1930, observed that when ${}^{9}_{4}Be$ is bombarded with α-particles, a highly penetrating radiation was produced. This radiation was supposed to be γ-rays. The reaction was supposed to be

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$$^{9}_{4}Be + ^{4}_{2}He \rightarrow ^{13}_{6}C + \gamma \text{ rays}$$

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However, when these supposed γ-rays were made to fall on a hydrogenous material, protons were knocked out. The K.E. of knocked out protons was determined. Using law of conservation of linear momentum, the energy of supposed γ-rays, was calculated. This energy was staggeringly high. It also appeared that law of conservation of energy was getting violated !

Chadwick; therefore, rejected the above reaction and said that the penetrating radiations emitted are *not* γ-rays. He proposed that the supposed γ-rays were, in fact, a neutral particle having a mass nearly same as that of a proton. He named this particle as a *neutron.* According to Chadwick,

$$^{9}_{4}Be + ^{4}_{2}He \rightarrow ^{12}_{6}C + ^{1}_{0}n$$

Q.111. *What is the mass of a neutron ?* **(1)**

Ans. Mass of neutron ≈ 1.01 a mU

Q.112. *Is free neutron a stable particle ?* **(1)**

Ans. No

Q.113. *For light nuclei what is the ratio of the number of protons and neutrons ?* **(1)**

Ans. 1

Q.114. *In heavy nuclei, is the ratio of the number of protons and the number of neutrons less than, greater than or equal to unity ?* **(1)**

Ans. Less than unity

Q.115. *Nucleus contains protons and neutrons and electrons around the nucleus. In an atom there are p protons, n neutrons and e electrons. For atoms of small mass, what is the relation between p, n and e ?* **(1)**

Ans. The number of protons is exactly equal to the number of electrons. The number of protons and neutrons is nearly same. Expressed mathematically;

$$n \approx p = e$$

Q.116. *How does nuclear density depend upon the size of the nucleus ?* **(1)**

Ans. The nuclear density is (very nearly) independent of the size of the nucleus.

Q.117. *Is the nuclear density same for all the elements ?* **(1)**

Ans. Yes

Q.118. *What is the relation between the radius of a nucleus and its mass number ?* **(1)**

Ans. The radius; R, of a nucleus of mass number A is given by the relation

$$R \propto A^{1/3} \quad \text{or} \quad R = R_0 A^{1/3}$$

Q.119. *What is ratio of radii of two nuclei of mass numbers A_1 and A_2 ?* **[C.B.S.E. 1995]**

Ans. $\dfrac{R_1}{R_2} = \left(\dfrac{A_1}{A_2}\right)^{1/3}$

Q.120. *What is atomic mass unit?* **(1)**

Ans. The atomic mass unit (or a.m.u) is $\dfrac{1}{12}$ th of the mass of $^{12}_{6}C$ atom. It is found that ;

$$1 \text{ a.m.u.} \approx 1.66 \times 10^{-27} \text{ kg}$$

Q.121. *What is the energy equivalent of the mass of the electron ?* **(1)**

Ans. Energy equivalent to mass of electron

$$= 9.1 \times 10^{-31} \times (3 \times 10^{8})^2 \text{ J}$$

$$= \frac{9.1 \times 10^{-31} \times 9 \times 10^{16}}{1.6 \times 10^{-13}} \text{ MeV}$$

$$\approx 0.51 \text{ MeV}$$

Q.122. *Show that 1 a.m.u. = 931 Mev* **(2)**

Ans. According to Einstein's mass energy equivalence relation, $E = mc^2$. Also 1 a.m.u.

$= 1.66 \times 10^{-27}$ kg.

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Therefore, energy equivalent of 1 a.m.u

$$= 1.66 \times 10^{-27} \times (3 \times 10^8)^2 \text{ J}$$

$$= \frac{1.66 \times 10^{-27} \times 9 \times 10^{16}}{1.6 \times 10^{-13}} \text{ MeV}$$

$$\approx 931 \text{ MeV}$$

Q.123. *What do you understand by the term ''mass defect'' ?*

Ans. For an atomic nucleus the sum of masses of proton and neutron, M, is always more than the actual mass *M'* of the nucleus. The difference between the two is known as mass defect (Δm), i.e., (1)

$$\Delta m = M - M'$$

Q.124. *Define binding energy of a nucleon. How is it related to mass defect ?*

Ans. The energy needed to break a nucleus into its constitutent particles is known as the binding energy. (2)

$$\text{B.E.} = \text{mass defect} \times c^2 = (\Delta m) \times c^2$$

Q.125. *Define binding energy per nucleon .*

Ans. Binding energy per nucleon is the ratio of the B.E. of the nucleus and the mass number (or total number of nucleons in the nucleus) B.E. per nucleon = $\frac{\text{B.E.}}{\text{Mass Number}}$ (1)

Q.126. *Obtain an expression for binding energy and binding energy per nucleon.*

Ans. The binding energy of a given nucleus ${}^{A}_{Z}X$ is given by B.E. = $(\Delta m) \times c^2$, where Δm, the mass defect, is given by $\Delta m = Zm_p + (A - Z)\, m_n - {}^{A}_{Z}M] \times C^2$ (2)

(m_p = mass of protons m_n = mass of neutron and ${}^{A}_{Z}M$ = mass of the given nucleus ${}^{A}_{Z}X$)

Thus, B.E. = $[Zm_p + (A - Z)\, m_n - {}^{A}_{Z}M \times c^2$

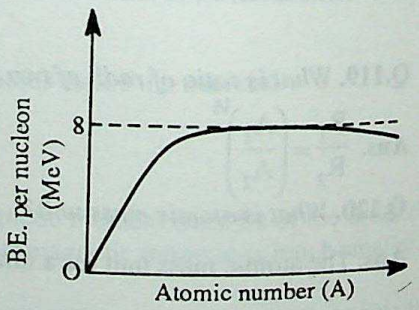
If we divide the B.E. by the total number (A) of nucleons, we get the B.E. per nucleon. Hence,

B.E. per nucleon = $\frac{\text{B.E.}}{A} = \frac{1}{A}[Zm_p + (A - Z)\, m_n - {}^{A}_{Z}M] \times c^2$

Q.127. *Show graphically how the binding energy per nucleon varies with atomic number. Write two main inferences drawn from the graph*

[C.B.S.E. 1995]

Ans. The curve of the B.E. per nucleon against the atomic number is as shown in Fig. 17. The curve shows the following characterstics :



(i) The B.E. per nucleon is low at the start of the periodic table. However, some of these light nuclei (e.g., ${}^{4}_{2}He$) are very stable because of a relatively large value of their B.E. per nucleon.

(ii) The B.E. per nucleon is (nearly) constant for most of the nuclei in the middle of the periodic table. The value of this B.E. per nucleon is nearly 8 MeV.

(iii) The B.E. per nucleon drops again to (relatively) much smaller values again towards the end of the periodic table.

The *packing fraction* of a given nucleus equals the ratio of its mass defect to its mass number i.e.,

packing fraction = $\frac{\text{mas defect}}{\text{mass number}}$

Q.128. *For greater stability a nucleus should have greater value of binding energy per nucleon. Why ?* (2)

Ans. The B.E. per nucleon is defined by

$$\text{B.E. per nucleon} = [Zm_p + (A - Z)\, m_n - {}^{A}_{Z}M] \times \frac{c^2}{A}$$

A greater value of this quantity, therefore, implies that a (relatively) greater fraction (of the total mass of its 'A' nucleons) has been converted into energy, during the process of formation of the nucleus. We can, thus,

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cause a disintegration of this nucleus only if it is 'supplied back' this 'lost' energy. The greater this 'lost energy', the more is the energy required to break the nucleus and the more stable the nucleus is. It follows that for greater stability, a nucleus should have a greater value of B.E. per nucleon.

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Q.129. *Name two atoms having exceptionally high value of binding energy per nucleon as compared to their neighbours.* **(1)**

Ans. $^{12}_{6}C$ and $^{16}_{8}O$

Q.130. *Which one has higher binding energy per nucleon* $^{235}_{92}U$ or $^{16}_{8}O$ *?*

Ans. $^{16}_{8}O$

Q.131. *In a nuclear reaction binding energy per nucleon of products is more than binding energy per nucleon of reactants. Is energy evolved or absorbed in this reaction ?* **(1)**

Ans. Energy is evolved.

Q.132. *In a nuclear reaction binding energy per nucleon of products is less than the binding energy per nucleon of reactants. Is energy released or absorbed in this reaction ?* **(1)**

Ans. Energy is absorbed.

Q.133. *The binding energy per nucleon versus mass number graph suggests the possibility of release of energy by nuclear fission and fusion. Explain how ?* **(2)**

Ans. We know that the binding energy per nucleon has lower value at the start and at the end of the periodic table compared to its value in the middle. It follows that when,

(i) Two light nuclei fuse together to form a heavier nucleus, there would be an increase in B.E. per nucleon. An increase in B.E. implies a decrease in mass, i.e., a conversion of mass into energy. This energy gets released out. The process of nuclear fusion, therefore, is accompanied by a release of energy.

(ii) A heavy nucleus breaks up into two (middle of the periodic table) fragments, we again have an increase in binding energy per nucelon. This implies a release of energy as explained above. Thus, the process of nuclear fission is also accompanied by a release of energy.

Q.134. *What is a nuclear reaction ?* **(1)**

Ans. A nuclear reaction is a reaction in which the atomic nucleus itself gets changed. This is usually achieved by bombarding the given nucleus with high energy particles like proton, α-particle or neutron.

Q.135. *Name two quantities that are conserved in a nuclear reaction.* **(1)**

Ans. Mass number and atomic number.

Q.136. *Explain how energy becomes available in a nuclear reaction.* **(2)**

Ans. The process of nuclear fission is initiated by letting a beam of (thermal) neutrons bombard a $^{235}_{92}U$ target. This resulting nuclear reaction can be of the form

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{144}_{56}Ba + ^{89}_{36}Kr + 3\,^{1}_{0}n + Q$$

'Q' here represents the energy released in the process. The energy is released because the sum total of the masses of the 'reactants' is greater than that of the 'resultants'. Hence, the reaction involves a conversion of mass into energy. We can write

$Q = [\{\text{Mass of } ^{235}_{92}U + \text{mass of neutron } ^{1}_{0}n - \{\text{Mass of } ^{144}_{56}U + \text{Mass } ^{89}_{36}Kr + \text{Mass of three } ^{1}_{0}n\}]\, xc^2$

The value of 'Q' is found to be nearly 200 MeV per fission.

Q.137. *A neutron is absorbed by a* $^{6}_{3}Li$ *nucleus with subsequent emission of an* α *particle. Write the corresponding nuclear reaction?* **(C.B.S.E. 1995)**

Ans. $^{6}_{3}Li + ^{1}_{0}n \rightarrow ^{3}_{1}H + ^{4}_{2}He$

Q.138. *Complete the following nuclear reactions:*

(i) $^{10}_{5}B + ^{1}_{0}n \rightarrow ^{7}_{3}Li + \ldots$

(ii) $^{19}_{9}F + ^{1}_{0}n \rightarrow ^{16}_{7}N + \ldots$

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Ans. (i) $^{10}_{5}B + {}^{1}_{0}n \rightarrow {}^{7}_{3}Li + {}^{4}_{2}He$

(ii) $^{19}_{9}F + {}^{1}_{0}n \rightarrow {}^{16}_{7}N + {}^{4}_{2}He$

Q.139. *In the reaction given below what is atomic number and mass number of element X ?*

$$^{198}_{80}Ag + {}^{1}_{0}n \rightarrow X + {}^{1}_{1}H$$

Ans. Mass number = 198, Atomic number = 79

Q.140. *Does the ratio of neutrons to protons in a nucleus increase, decrease or remain same after the emission of an alpha particle ?* **[C.B.S.E. 1994]**

Ans. Let the number of neutrons and protons in the original nucleus be N and Z respectively. Now an alpha particle, being made up of 2 neutrons and 2 protons, we have the number after the emission as (N – 2) and (Z - 2) respectively. Thus,

$$\frac{N-2}{Z-2} > \frac{N}{Z}$$

if $NZ - 2Z > NZ - 2N$ or if $(-2Z) > (-2N)$

or if $Z < N$

This is usually the case. Hence, the ratio usually increases. However, if N = Z, the ratio would remain the same. And if Z > N, the ratio would decrease. The latter two possibilities are unlikely for alpha emitters. Hence, the ratio usually increases.

Q.141. *A neutron strikes a $^{10}_{6}B$ nucleus with the subsequent emission of an alpha particle. Write the corresponding nuclear reaction. Find the atomic number, mass number and chemical name of the remaining nucleus.* **[C.B.S.E. 95 Comptt.]**

Ans. $^{10}_{6}B + {}^{1}_{0}n \rightarrow {}^{7}_{4}Be + {}^{4}_{2}He$

Atomic number = 4, Mass number = 7

The chemical name of the resulting nucleus is beryllium.

Q.142. *What do you understand by the term nuclear fission ?* (1)

Ans. Nuclear fission is the phenomenon of splitting up of a heavy nucleus like $^{235}_{92}U$ into two nearly equal fragements, when it $\left(^{235}_{92}U\right)$ is bombarded wih slow (thermal) neutrons.

Q.143. *How was the phenomenon of nuclear fission discovered ?* (2)

Ans. *Enrico Fermi*, in 1934, conducted experiments bombarding $^{235}_{92}U$ nucleus with slow neutrons. The products obtained showed radioactivity. The half-life of various radioactive radiations was determined. Fermi thought that each half-life corresponded to a *transuranium element.* The proposed reaction was

$$^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{236}_{92}U \rightarrow {}^{236}_{93}X + {}^{0}_{-1}e \rightarrow {}^{236}_{94}Y + {}^{0}_{-1}e$$

$$\downarrow$$

$$^{236}_{95}Z + {}^{0}_{-1}e$$

X, Y and Z are isotopes of element 93, 94 & 95. However, it was in 1939; that *Otto Hahn* and *F. Strassmann;* discovered that the products obtained, when $^{235}_{92}U$ was bombarded with neutrons, were not transuranium elements but a number of different elements nearly all of which lie near the middle of the periodic table. In other words, a uranium nucleus, after the capture of a single neutron; splits up into two nearly equal fragments. This process was called nucleus fission.

Q.144. *What is the (approximate) release of energy per fission of $^{235}_{92}U$ nucleus ?* (1)

Ans. About 200 MeV.

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Q.145. *What is the average number of neutrons emitted per fission of* $^{235}_{92}U$ *?* **(1)**

Ans. Three

Q.146. *Is* $^{238}_{92}U$ *easily fissionable ?* **(1)**

Ans. No

Q.147. *Are the neutrons produced due to fission of a* $^{235}_{92}U$ *atoms slow or fast neutrons ?* **(1)**

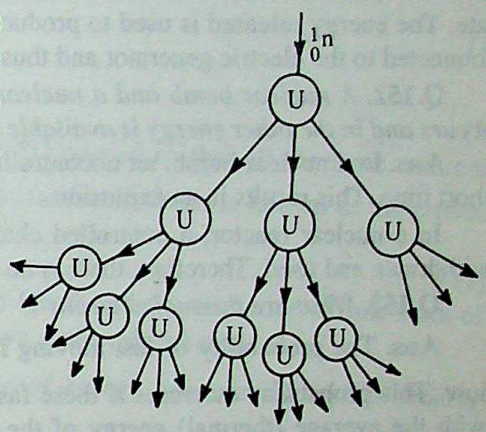
Ans. Fast neutrons

Q.148. *What is a self sustained nuclear reaction ?* **(1)**

Ans. A self sustained nuclear reaction is one that, once initiated, keeps on 'going on', without any further need of any external 'missiles'.

Q.149. *What is an uncontrolled chain reaction ? Explain.* **(2)**

Ans. If all the three neutrons, emitted due to the fission of one atom of $^{235}_{92}U$, cause fission of three more $^{235}_{92}U$ atoms and the process repeats itself, a very large amount of energy is released in a very short time. This results in an explosion. Such a reaction is known as an uncontrolled chain reaction. Fig. shows an uncontrolled chain reaction.



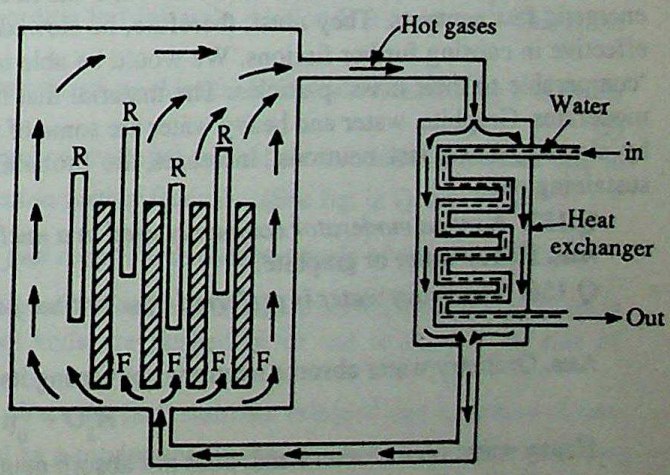
Q.150. *Explain why is* $^{238}_{92}U$ *not suitable for nuclear fission.*

Ans. $^{238}_{92}U$ is the major component (more than 99%) of natural uranium. It has the property of readily capturing even fast neutrons. But this capture does not send it into those convulsions which may result in its breaking up into the fragments. Further, the probability of its capturing slow neutrons is rather low. Neutron impact, therefore, does not cause any significant fissions in this abundant isotope of uranium and it is, therefore, not suitable for nuclear fission.

The 'suitable for fission' isotope of uranium is $^{235}_{92}U$ which has a very high probability of capturing slow neutrons and then undergoing fission. The process of increasing the percentage of this isotope, in natural uranium, is often referred to as *'enrichment'* of uranium. In enriched uranium, the content of $^{235}_{92}U$ is up to 3% instead of its normal value of only about 0.75%.

Q.151. *Explain the principal of the working of a nuclear reactor?* **(2)**

Ans. The fission based nuclear reactors, in use at present, are devices for producing nuclear (fission) energy in a controlled way. As we know, the fission of uranium, by neutrons, is a self sustaining chain reaction in which 2.5 neutrons per fissions are produced on the average. The reaction can, therefore, proceed in a sustained and controlled way if one of these neutrons, is able to cause further fission and the remaining '1.5' neutrons are allowed to escape. To meet these requirement, the nuclear reactor is made sufficiently large (to increase the surface/volume ratio to the desired optimum level). Further, if need be, the fuel is also surrounded by a neutron reflecting material. This helps to decrease the 'neutron loss' if it is sufficiently fast.



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The essential parts of a nuclear reactor are shown in the figure. These are :

(i) the *fissionable fuel* (like enriched uranium) taken usually in the form of rods. (ii) the control rods made of some suitable neutron absorbing material (like cadmium.) They are pushed in or out to control the rate of neutron absorption and hence the rate of further fissions. (iii) the moderator (like graphite, the water or heavy water) that helps to slow down the fast neutrons and, thus, increases the probability of their capture by $^{235}_{92}U$ nuclei. It shares the energy of the fast moving neutrons without actually absorbing them.

The moderator is preferably a material whose (atomic) mass is comparable to that of the neutron and which, therefore, causes a large energy exchange on each collision. It is suitably 'mixed' with the uranium fuel.

The nuclear reactor goes into operation when some stray neutrons initiate fission in the enriched uranium fuel. The moderator and the control rods are then suitably adjusted to sustain the chain reaction at a controlled rate. The energy released is used to produce steam in a steam engine. This steam then drives the steam turbines connected to the electric generator and thus help to produce electricity.

Q.152. *A nuclear bomb and a nuclear reactor work on the same principle. Explain why in one explosion occurs and in the other energy is available at a steady rate ?* (2)

Ans. In a nuclear bomb, an uncontrolled chain reaction takes place. Very large energy is released in a very short time. This results in an explosion.

In a nuclear reactor, a controlled chain reaction. occurs. Energy is released at such a rate that it can be withdrawn and used. Therefore, there is no explosion.

Q.153. *What are thermal neutrons ?* (2)

Ans. The probability of fast moving neutrons, colliding with $^{235}_{92}U$ nuclei and, producing fissions is rather low. This probability increases if these fast moving neutrons are slowed down to energies that are comparable with the average (thermal) energy of the atoms/molecules at temperatures of the order of the average room temperature (~300 K). When the neutrons are slowed down to such energies, (less than 1 eV at typical reactor operating temperatures), they are referred to as thermal neutrons.

Thermal neutrons are extensively used in 'fission reaction' as their 'reaction cross section' (indicative of the probability of reaction) for fission of $^{235}_{92}U$ is quite high.

Q.154. *What is the name of the first reactor in India ?* (1)

Ans. Apsara

Q.155. *Name the fuel used in a nuclear reactor.* (1)

Ans. Enriched $^{235}_{92}U$

Q.156. *What is the action of a moderator in a nuclear reactor ?* (1)

Ans. We know that the probability of causing further fissions increases if the neutrons are (relatively slow) thermal neutrons rather than fast neutrons. Now the neutrons produced, as a product of a fission, are extremely energetic fast neutrons. They must, therefore, be slowed down (to become thermal neutrons) if they have to be effective in causing further fissions. We would be able to slow them effectively if they are made to collide with 'comparable to their mass' particles. The material that helps in the slowing down of fast neutrons is known as moderator. Graphite, water and heavy water are some of the commonly used moderators. It is the moderator that, by slowing down fast neutrons, increases the probability of further fissions and makes the reaction a self sustaining one.

Q.157. *Name a moderator commonly used in a nuclear reactor.* (1)

Ans. Heavy water or graphite.

Q.158. *Why heavy water is preferred over ordinary water, as a moderator in a nuclear reactor ?* **[C.B.S.E 1994]** (1)

Ans. Ordinary water absorbs neutrons converting itself into heavy water according to the reaction.

$$H_2O + {}^{1}_{0}n \rightarrow D_2O$$

Heavy water on the other hand, does not absorb neutrons. It only slows down the fast neutrons.

Q.159. *What is the role of control rods in a nuclear reactor?* (1)

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Ans. The control rods are used to control the rate of absorption of neutrons produced in the fission reaction. They are, therefore, used to prevent the fission reaction from going to explosive limits or from stopping completely.

Q.160. *Name the material used as ''control rods'' in a nuclear reactor.* **(1)**

Ans. Cadmium.

Q.161. *Why are cadmium rods used as ''control rods'' in a nuclear reactor ?* **(1)**

Ans. Control rods are made of cadmium because cadmium nuclei possess the property of rapidly capturing (or absorbing) slow or thermal neutrons.

Q.162. *What is a breeder reactor ?* **(1)**

Ans. A breeder reactor is used to convert $^{238}_{92}U$ into *plutonium.*

Q.163. *What raw material is used in a breeder reactor ?* **(1)**

Ans. $^{238}_{92}U$

Q.164. *What is critical mass ?* **(1)**

Ans. In an uncontrolled chain reaction the minimum mass of $^{238}_{92}U$ needed so that all the three neutrons produced due to fission of one atom, are absorbed and, do not cause further fissions, is known as the critical mass.

Q.165. *What is critical size ?* **(1)**

Ans. The size of nuclear fuel needed, so that the three neutrons (produced due to fission of one atom of $^{235}_{92}U$) are not able to escape out without causing further fission, is known as the critical size.

Q.166. *What is meant by nuclear fission ? Explain the source of energy released during the process represented by the equation .*

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U \rightarrow ^{90}_{38}Si + ^{143}_{54}Xe + 3\,^{1}_{0}n$$

Ans. Nuclear fission is a process in which a heavy nucleus like $^{235}_{92}U$ breaks up into two nearly equal fragments when bombarded with suitable energetic particles, like neutrons.

The given reaction is

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U \rightarrow ^{90}_{38}Si + ^{143}_{53}Xe + 3\,^{1}_{0}n$$

M = Sum of masses of reactants = Mass of $^{235}_{92}U$ + Mass of neutron

M′ = Sun of masses of products = Mass of $^{90}_{38}Si$ + Mass of $^{143}_{53}Xe$ + 3 × Mass of neutron.

It is found that M > M′. The mass defect (Δm) of the reaction is

$\Delta m = M - M'$, a positive quantity

It is this mass (Δm) that is converted into energy according to Einstein's relation $E = (\Delta m) \times c^2$. This is the source of energy in the reaction.

Q.167. *What is controlled nuclear chain reaction? Describe how this can be achieved indicating briefly the function of each part of the reactor?* **(3)**

Ans. A controlled chain reaction is one in which, on the average; two of three neutrons emitted due to fission of one atom of $^{235}_{92}U$ are absorbed before they can cause further fission. (See fig. in Q. no. 151)

Fig. shows essentials of a nuclear reactor. (i) F, F are *fuel rods.* These rods are made of enriched $^{235}_{92}U$.

(ii) R, R are the *control rods.* The control rods are made of a material that can absorb neutrons. Cadmium is commonly used as the control rod material. The control rods are pushed in or out to control the rate of absorption of neutrons.

(iii) *Moderator.* It is a material that helps in slowing down the fast neutrons, released due to fission of one atom of $^{235}_{92}U$. Heavy water or graphite, is commonly used as a moderator. When fast neutrons collide with the

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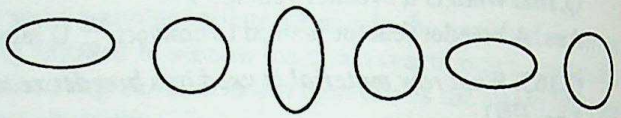
atoms of moderator, sharing of energy takes place. Consequently, neutrons are slowed down without absorption. The moderator is mixed suitably with the maximum fuel.

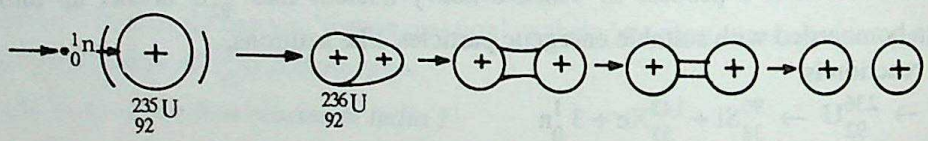
(iv) *Heat exchanger.* The energy releaed due to fission is withdrawn from reactor using a heat exchanger. Some inert gases are made to pass through the reactor. These gases become hot. In a heat exchanger these hot gases transfer their energy to the external system.

Q.168. *Explain how the phenomenon of nuclear fission can be explained on the liquid drop model of the nucleus* (3)

Ans. The liquid drop model of the nucleus was proposed by Bohr and Wheeler. In this model, the nucleus was likened to a drop of liquid. A liquid drop, when 'distorted', can vibrate in a variety of ways. Thus, in a possible mode, it can become a prolate spheriod, an oblate spheroid, a sphere, a prolate spheroid again and so on as shown in fig. alongside. The forces involved here are those of surface tension and the inertia of moving liquid molecules.



In a nucleus, the nuclear force tend to keep the nucleus intact while the repulsive electrostatic forces between protons tend to distort it. Whereas, the former are short ranged, the latter are long ranged ones. Hence, when a nucleus gets distorted, the nuclear forces (the nuclear surface tension forces) restore it to its origional condition if the distortion is small enough. However, if the distortion is large enough, the nuclear particles get widely separated and the (short ranged)nuclear forces no longer remain operative. The (long range) repulsive forces are, however, still operative and these lead to, break up of the nucleus into parts. It is assumed that the impact of a neutron, on $^{235}_{92}U$, puts the resulting 'nuclear drop' into such convulsions that ultimately lead to its breaking into two fragments with some neutrons also escaping out of the nucleus. We can picturise the fission process as shown in the figure below.



Q.169. *What is a 'thermo nuclear'' reaction ?* (1)

Ans. The fusion (joining together) of two light nuclei occurs at very high temperature (of the order of 5000 K). This is known as a thermo-nuclear reaction.

Q.170. *What do you understand by nuclear fusion ?* (1)

Ans. The joining together of two light nuclei resulting in the formation of a heavier nucleus, is known as nuclear fusion.

Q.171. *Define disintegration constant and mean life of a radioactive substance. Give the unit for each.* **(CBSE 1997)** (2)

Ans. *Disintegration constant:* It is the reciprocal of time at the end of which the number of atoms left undecayed in a radioactive sample reduces to $\frac{1}{e}$ times the original number of atoms. Its unit is s^{-1}.

Mean life: Mean life of a radioactive substance is the average time for which atoms of that substance actually live before decaying. Its unit is second.

Q.172. *Define the term binding energy of a nucleus. Compute binding energy/nucleon for $^{56}_{26}Fe$. Given, mass of proton = 1.0078254 u, mass of neutron = 1.0086654 u, mass of $^{56}_{26}Fe$ nucleons = 55.9349394 u, and 1 u = 931.5 MeV,* **(CBSE 1998)** (3)

Ans. Binding energy. The energy needed to break a nucleus into its constitutent particles is known as the binding energy.

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$m_{Fe} = 55.9349394$ amu, $m_n = 1.0086654$ amu

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$m_p = 1.0078254$ amu, $^{56}_{26}Fe$ has 26 protons and 30 nuetrons.

So, mass defect, $\Delta m = (30\, m_n + 26\, m_p - m_{Fe})$

$= (30.25992 + 26.20345 - 55.934939) = 0.528431$ amu

$\therefore$ Binding energy per nucleon $= \dfrac{931.5 \times 0.528431}{56}$ meV $= 8.79$ meV

Q.173. *Will the neutron to proton ratio increase or decrease for nucleus of an element during: (i) beta decay (ii) alpha decay? Support your answer using suitable examples.*

(CBSE 1999) (3)

Ans. (i) During β-decay, mass number remains same and atomic number increases, hence, neutron to proton ratio decreases.

(ii) During α-decay, mass number and atom number both decrease; hence, neutron proton ratio increases.

Q.174. *Explain the process of release of energy in a nuclear reactor. Draw a labelled diagram of a nuclear reactor and write the function of each part.* **(CBSE 1997)(5)**

Ans. See answer to question 151.

Q.175. *Compare the radii of two nuclei with mass number 1 and 27 respectively.* **(CBSE 2000) (1)**

Ans. $\dfrac{R_1}{R_2} = \left(\dfrac{A_1}{A_2}\right)^{1/3} = \left(\dfrac{1}{27}\right)^{1/3} = \dfrac{1}{3} = 1 : 3$

Q.176. *Some scientists have predicted that a global nuclear war on earth would be followed by nuclear winter. What would cause nuclear winter?* **(CBSE 1999) (3)**

Ans. After a global nuclear war a large amount of nuclear waste will generate, which will decrease in greenhouse effect for some period of time. Due to decrease in greenhouse effect, the earth will not further warm due to traping of energy. Consequently the earth will become cool, resulting into nuclear winter.

Q.177. *What is the temperature at which fusion is possible ?* **(1)**

Ans. About 5000 K – 6000 K

Q.178. *Name the necessary conditions required to carry out a fusion reaction* **(2)**

Ans. (i) The nuclei undergoing fusion must possess energies high enough to overcome their mutual electrostatic repulsive force.

(ii) The nuclei must remain confined to a limited volume for a sufficiently long time so that they may undergo many collisions before getting lost either by escaping from the surface or by absorption.

Q.179. *Which one is more devastating : a hydrosgen bomb or a nuclear bomb ?* **(1)**

Ans. Hydrogen bomb.

Q.180. *Can fusion reaction be controlled in a sustained way ?* **(1)**

Ans. No.

Q.181. *A fusion reaction is more energetic than a fission reaction. Why ?* **(2)**

Ans. In a fission reaction energy released due to fission of one atom of $^{235}_{92}U$ is about 200 MeV.

Therefore, energy released per nucleon $= \dfrac{200}{235} \approx 0.8$ MeV. The energy released when four protons combine to form a helium atom is about 28 MeV. Therefore, energy released per nucleon $= \dfrac{28}{4} = 7$ MeV ! Since energy released per nucleon in fusion reaction is more than energy released per nucleon in fission process; fusion reaction is more energetic.

Q.182. *Fusion reactors are reactors of future comment* **(2)**

Ans. Both the reaction of nuclear fusion and nuclear fi sion yield much more energy than the other conventional nuclear reactions. They can, therefore, be put to use to generate energy. Whereas fission based reactors are already being used to generate electricity, fusion based controlled reactors have so far not become a

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practical possibility. They are, however, reactors of the future because of their many advantages over the fission reactions. Some of these advantages are :

(i) the basic fuel, hydrogen and deuterium, is available almost in unlimited quantities in sea water etc. (ii) the energy yield per unit mass of the fuel is much more in fusion than in fission. (iii) there are no radioactive pollutants arising as a by product of the fusion reactions. One the other hand, fission results in some radioactive isotopes that are quite long lived and, therefore, almost a permanent source of radioactive pollution.

Because of these advantages, scientists are keenly exploring the possibility of a fusion reactor. It is clear that fusion holds the promise of meeting the energy requirements challenge of the future. Hence, fusion reactors are indeed the reactors of future.

Q.183. *What is a ''magnetic bottle''?* (2)

Ans. It is known that fusion reacion becomes a practical possibility only if the 'fuel' nuclei are at temperatures that are very very high. It is also obvious that no conventional container can hold on the fuel, that is, maintained at such high temperatures. Scientist, therefore, are looking for unconventional means of confining the fuel in a given region of space. Since at these high temperatures, the fuel will be in the plasma (completely ionised) state, a magnetic field could 'perhaps' be used to contain the plasma. Scientists are so far been able to achieve only very limited success in this direction. The magnetic field configurations used have succeeded in containing the plasma only for a very small fraction of a second. However, since it is the magnetic field configuration that momentarily confines the plasma, the arrangement has often been referred to as a magnetic bottle.

The 'magnetic bottle' is really based on the reflection of an ion moving in a magnetic field whose lines of force are converging. We use a pair of such fields to confine the plasma in a limited region.

Q.184. *What is the source of radiant energy of the sun ?* (2)

OR

How does the solar energy arise ? (2)

Ans. We now believe that the process of nuclear fusions is the main source of the energy of the Sun (and the stars). In the interior of the Sun (and the stars), where extremely high temperatures prevail, conditions are just right for the fusion of hydrogen into helium. This process is accompanied by the release of large amounts of energy which sustains the Sun (and the stars).

The process of fusion of hydrogen nuclei to form helium takes place either by the proton-proton or through the carbon-cycle, the reaction may be represented as

$$4\,{}^{1}_{1}H \rightarrow {}^{4}_{2}He + 2\,{}^{1}_{0}e + 4\bar{\nu} + \text{energy} \quad (\approx 24.7\ \text{MeV})$$

It is believed that once the hydrogen fuel present in a star gets consumed, the star dies out. In the case of the Sun, the process is likely to take a few billion years more before the Sun 'fades' out.

Q.185. *What is proton-proton cycle ?* (2)

Ans. The proton - proton cycle represents one of the 'models' of fusion of four hydrogen nuclei to form a helium nucleus. The various 'steps' in the cycle are listed below :

$${}^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + {}^{0}_{1}e + \nu \quad ...(1)$$

$${}^{1}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + \gamma \quad ...(2)$$

$${}^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + {}^{1}_{1}H + {}^{1}_{1}H \quad ...(3)$$

Thus, (i) two protons combine to form a deutrium nucleus and a positron (ii) a third proton and the deutrium combine to form a ${}^{3}_{2}He$ nucleus (iii) two ${}^{3}_{2}He$ nuclei combine to fom a ${}^{4}_{2}He$ nucleus and give back two protons.

The end result of the cycle is thus the combination of four protons to form a helium nucleus and two positrons. The total energy evolved in the process work out to be 24.7 MeV. Thus, the energy release per ${}^{1}_{1}H$ nucleus 'consumed' is nearly 6.2 MeV.

Q.186. *Give the features of carbon cycle of nuclear fusion .* (2)

Ans. The carbon cycle is believed to be the mode of fusion of (4) hydrogen nuclei to form a helium nucleus in the interior of stars that are hotter than the Sun.

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The cycle is believed to proceed in the following way.

$$^{1}_{1}H + ^{12}_{6}C \rightarrow ^{13}_{7}N + \gamma$$

$$^{13}_{7}N \rightarrow ^{13}_{6}C + ^{0}_{1}e + \gamma$$

$$^{1}_{1}H + ^{13}_{6}C \rightarrow ^{14}_{7}N + \gamma$$

$$^{1}_{1}H + ^{14}_{7}N \rightarrow ^{15}_{8}O + \gamma$$

$$^{15}_{8}O \rightarrow ^{15}_{7}O + ^{0}_{1}e + \gamma$$

$$^{1}_{1}H + ^{15}_{7}N \rightarrow ^{12}_{6}C + ^{4}_{2}He$$

The overall result is the combination of four hydrogen nuclei to form a helium nucleus plus two positrons in the same way as in the proton - proton cycle. The energy yield is also the same – 24.7 MeV, i.e., nearly 6.2 MeV per proton 'consumed'. Since the initial $^{12}_{6}C$ reappears at the end, it can be treated as a kind of 'catalyst' for the reaction.

SOLVED NUMERICAL PROBLEMS ON UNIT – XI

Example 1. *Calculate the distance of closest approach of α-particle of energy 2.0 MeV being scattered by a gold nucleus (Z = 79).*

Solution : Let a be the distance of the closest approach of the α-particle to the gold nucleus. In this position, the entire initial K.E. (E) of α-particle is converted into potential energy. Therefore,

$$E = \frac{1}{4\pi\varepsilon_o}\frac{(Ze)(2e)}{a} \quad \text{or} \quad a = \frac{1}{4\pi\varepsilon_o}\left(\frac{2Ze^2}{E}\right)$$

Given

$$E = 2.0 \text{ MeV} = 2.0 \times 1.6 \times 10^{-13} \text{J}, \; e = 1.6 \times 10^{-19} \text{ C}$$

$$\therefore \quad a = 9 \times 10^9 \times \frac{2 \times 79 \times (1.6 \times 10^{-19})^2}{2.0 \times 1.6 \times 10^{-13}} = \frac{9 \times 10^9 \times 2 \times 79 \times 1.6 \times 10^{-25}}{2.0} \text{ m}$$

$$a = \mathbf{7.584 \times 10^{-14}\ m}$$

Example 2. *Calculate the distance between two protons such that the electrical repulsive force between them is equal to the weight of either.* **(CBSE 1994)**

Solution : Let 'r' be the required distance. We then have

$$\frac{1}{4\pi\varepsilon_o}\frac{q^2}{r^2} = mg$$

where q and m stand, respectively, for the charge and mass of the proton. Hence,

$$r^2 = \frac{1}{4\pi\varepsilon_o}\frac{q^2}{mg}$$

$$= 9 \times 10^9 \times \frac{(1.6 \times 10^{-19})^2}{1.6 \times 10^{-27} \times 9.8} \text{ m}^2$$

$$= \frac{9 \times 1.6 \times 10^{-29}}{9.8 \times 10^{-27}} \text{ m}^2 = 1.46 \times 10^{-2} \text{ m}^2$$

$$\therefore \quad r = \sqrt{0.014}\,\text{m} = 0.12 \text{ m} = \mathbf{12 \text{ cm}}$$

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Example 3. *Show that the velocity of the electron in the first orbit is (1/137) c, where c is the velocity of light.*

Solution : The velocity of electron in the nth orbit is given by $v_n = \dfrac{2\pi Ze^2}{(4\pi\varepsilon_o)nh}$

For hydrogen the velocity in the first orbit is given by

$$v_1 = \frac{2\pi e^2}{(4\pi\varepsilon_o)\,h} = \frac{2 \times 3.142 \times (1.6 \times 10^{-19})^2 \times 9 \times 10^9}{6.6 \times 10^{-34}} = 2.19 \times 10^6 \text{ m/s}$$

$$\therefore \quad \frac{v_1}{c} = \frac{2.19 \times 10^6}{3 \times 10^8} = \frac{0.73}{100} = \frac{1}{137}$$

Example 4. *Determine the speed of the electron in the n = 3 orbit of He^+.*

Solution : The velocity of the electron in a permitted orbit in accordance with Bohr's theory is given by

$$v = \frac{2\pi Ze^2}{nh} \cdot \frac{1}{4\pi\varepsilon_o} = \frac{Ze^2}{2\varepsilon_o nh}$$

We are given that Z = 2 and n = 3

$$\therefore \quad v = \frac{2 \times (1.6 \times 10^{-19})^2}{2 \times 8.854 \times 10^{-12} \times 3 \times 6.6 \times 10^{-34}} = \mathbf{1.46 \times 10^4 \ ms^{-1}}$$

Example 5. *Calculate the radius of the first orbit of hydrogen atom.*

OR

Calculate the value of Bohr radius.

Solution : The radius of nth orbit is given by the relation $\gamma_n = \dfrac{n^2h^2(4\pi\varepsilon_o)}{4\pi^2 mZe^2}$

For the first orbit n = 1 and for hydrogen Z = 1.

$$\therefore \quad r_1 = \frac{h^2(4\pi\varepsilon_o)}{4\pi^2 me^2}$$

$$\therefore \quad r_1 = \frac{(6.6 \times 10^{-34})^2}{9 \times 10^9 \times 4 \times (3.142)^2 \times (9.1 \times 10^{-31})(1.6 \times 10^{-19})^2}$$

$$= 0.5292 \times 10^{-10} \text{ m} = \mathbf{0.53\ A}$$

Example 6. *The total energy of an electron in the first excited state of the hydrogen atom is about – 3.4 eV. What is the kinetic energy of the electron in this state?* **(CBSE 1995)**

Solution : The kinetic energy would equal (about) **+ 3.4 eV**

(Note : For the electron in the hydrogen atom.

| K.E. | = | total energy | = ½ | P.E | . The P.E. and total energy are both negative (the electron being a 'bound' particle) while the kinetic energy is positive.

Example 7. *The total energy of an electron in the first excited state of the hydrogen atom is – 3.4 eV. What are the values of potential and kinetic energies of the electron in this state?*

Solution : We have K.E. = – total energy **(CBSE 1993 Comptt.)**

$$= -(-3.4 \text{ eV}) = \mathbf{+3.4\ eV}$$

Also, P.E. = 2 (total energy)

$$= 2 \times (-3.4 \times \text{eV}) = \mathbf{-6.8\ eV}$$

Example 8. *The energy of an electron in the nth orbit of hydrogen atom is given by $(-13.6/n^2)$ eV. How much energy is required to take an electron from the ground state in the first excited state?*

(CBSE 1993; CBSE 1994)

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Solution : We have, energy in the nth orbit $= \dfrac{-13.6}{n^2}$ eV

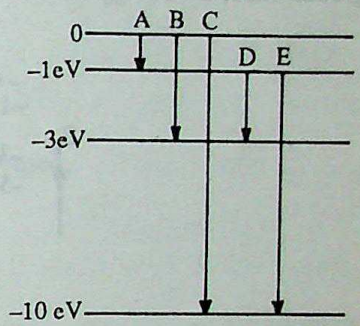
$\therefore$ Energy of the ground state (n = 1) = – 13.6 eV

and Energy of the first excited state (n = 2) = $\dfrac{-13.6}{4}$ eV = – 3.4 eV

$\therefore$ Energy required for the excitation (– 3.4 eV) – (– 13.6 eV) = **+ 10.2 eV**

Example 9. *The energy levels of an atom of an element X are shown in the diagram. A photon of wavelength 620 nm is emitted. This corresponds to which of the transitions : A, B, C, D or E ?*

(CBSE 1993 Comptt., CBSE 1997)



Solution : The energy (in eV) of a photon of wavelength λ angstorm is given by

$$E = \frac{h\,c}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{\lambda}$$

$$= \frac{6.6\times10^{-34}\times3\times10^{8}}{620\times10^{-9}} = 3.2\times10^{-19}\ \text{J}$$

$$= \frac{3.2\times10^{-19}}{1.6\times10^{-19}}\ \text{eV} = \mathbf{2eV}$$

It is clear that the enrgy released during the transition D is 2 eV. *Hence, the required transition is D.*

Example 10. *Calculate the value of the Rydberg constant for ordinary hydrogen, given the wavelength of H_α line as 6553 Å.*

Solution : We know that for Balmer series: $\bar{\nu} = \dfrac{1}{\lambda} = R\left(\dfrac{1}{2^2} - \dfrac{1}{n^2}\right)$

Since λ for the first line of Balmer series is given to be 6553 A,

We have $\dfrac{1}{6553\times10^{-10}} = R\left(\dfrac{1}{2^2} - \dfrac{1}{3^2}\right) = R\left(\dfrac{1}{4} - \dfrac{1}{9}\right) = R\times\dfrac{5}{36}, \Rightarrow R = \dfrac{36\times10^{10}}{5\times6553} = \mathbf{1.098\times10^{7}\ m^{-1}}$

Example 11. *The Rydberg constant for hydrogen is 10967700 m^{-1}. Calculate the short and long wavelength limits of Lyman series.*

Solution : For Lyman series, the wave number is given by $\bar{\nu} = \dfrac{1}{\lambda} = R\left(\dfrac{1}{1^2} - \dfrac{1}{n^2}\right)$

For short wavelength limit n = ∞ and let $\lambda = \lambda_S$

$$\therefore \bar{\nu}_s = \frac{1}{\lambda_s} = R\left(\frac{1}{1} - \frac{1}{\infty}\right) = R$$

$$\therefore \lambda_S = \frac{1}{R} = \frac{1}{10967700}\ \text{m} = \frac{10^{10}}{10967700}\ \text{Å} = 911.6\ \text{Å}$$

For long wavelength limit, n = 2 and let $\lambda = \lambda_L$

$$\bar{\nu}_L = \frac{1}{\lambda_L} = R\left(\frac{1}{1^2} - \frac{1}{2^2}\right) = R\left(1 - \frac{1}{4}\right) = \frac{3}{4}R$$

$\therefore$

$$\lambda_L = \frac{4}{3R} = \frac{4\times10^{10}}{3\times1096700}\ \text{Å} = \mathbf{1215\ Å}$$

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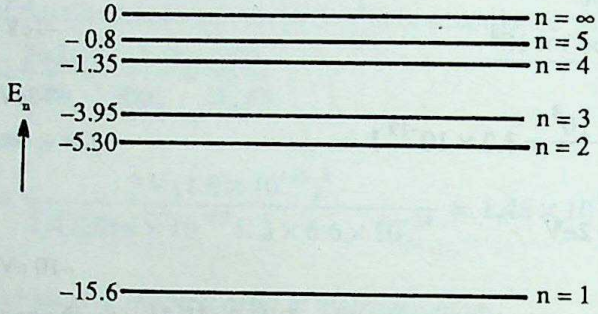
Example 12. *Some of the energy levels of a hypothetical one electron atom (not hydrogen) are as follows :*

n	1	2	3	4	5	∞
E_n (eV)	–15.6	–5.30	–3.98	–1.35	–0.80	0

Draw the energy level diagram.

Calculate the frequency of photon emitted when the atomic system goes from energy state n = 3 to the ground level.

Solution : Energy level diagram is as shown in the figure and is self explanatory. For the transition n = 3 to the ground state, the energy emitted is given by



$$= -3.98 - (-15.6)\ \text{eV} = 11.62\ \text{eV} = 11.62 \times 1.6 \times 10^{-19}\ \text{joule}$$

$$h\nu = 11.62 \times 1.6 \times 10^{-19} \quad \nu = \frac{11.62 \times 1.6 \times 10^{-19}}{6.6 \times 10^{-34}} \ \frac{\text{joule}}{\text{joule} - \text{s}}$$

$$= \frac{11.62 \times 1.6}{6.6} \times 10^{15} = 2.817 \times 10^{15}\ \text{Hz}$$

Example 13. *State Bohr's postulates for hydrogen atom. The wavelength of the first spectral line. of Balmer series in hydrogen spectrum is 6560 Å. Calculate the wavelength of second spectral line of Lyman series. Ionisation energy of hydrogen atom is 13.6 eV.* **(CBSE 1998)**

Solution: See theoretical section for 1st part.

$$\lambda_{B_1} = 6560\ \text{Å},\ \text{I.E. of H-atom} = 13.6\ \text{eV},\ \lambda_{B_2} = ?$$

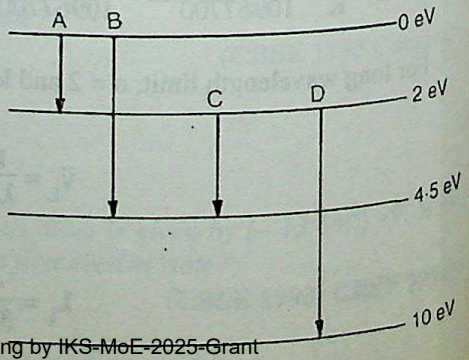
$$E_n = -\frac{13.6}{n^2}\ \text{eV} \Rightarrow E_1 = -13.6\ \text{eV},\ E_2 = -3.4\ \text{eV},\ E_3 = -1.51\ \text{eV}$$

$$\lambda_{B_1} = \frac{hc}{E_3 - E_2},\ \lambda_{L_2} = \frac{hc}{E_2 - E_1}$$

$$\therefore \frac{\lambda_{B_1}}{\lambda_{L_2}} = \frac{E_2 - E_1}{E_3 - E_2} = \frac{-3.4 + 13.6}{-1.51 + 3.4} = \frac{10.2}{1.89}$$

$$\Rightarrow \lambda_{L_2} = \frac{1.89}{10.2} \times 6560 \approx \mathbf{1216\ Å}$$

Example 14. *The energy level of an atom are as shown below. Which of them will result in the transition of a photon of wavelength 275 nm?* **(CBSE 1999)**



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Solution: $\Delta E = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{275 \times 10^{-9}}$ J $= 0.072 \times 10^{-17}$ J

$$= \frac{0.072 \times 10^{-17}}{1.6 \times 10^{-19}} \text{ eV} = 4.5 \text{ eV}$$

Hence, transmission B will result in required emission.

Example 15. *Sate the postulates of Bohar's model of hydrogen atom. The electron in a given Bohr orbit has a total energy of – 1.5 eV. Calculate its (i) kinetic energy (ii) potential energy. (iii) wavelengthof light emitted, when the electron makes a transition to the ground state.*
(Ground state energy = – 13.6 eV) **(CBSE 2000)**

Solution: See theoretical section for 1st part.

Total energy = – 1.5 eV

(i) K.E. = – E = **+ 1.5 eV**

(ii) P.E. = – 2 × K.E. = – 2 × 1.5 = **– 3 eV**

(iii) When the electron makes transition to the ground state, energy released,

$$\Delta E = -1.5 - (-13.6) = 12.1 \text{ eV}$$

$$\Delta E = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{\Delta E} = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{12.1 \times 1.6 \times 10^{-19}}$$

1.0227×10^{-7} m = 1022.7 Å = **1023 Å**

Example 16. *The value of ground state energy of hydrogen atom is – 13.6 eV.*
(i) What does the negative sign signify?
(ii) How much energy is required to take an electron in this atom from the ground state to the first excited state? **(CBSE 2000)**

Solution: (i) The negative sign shows that the electron is bound to the nucleus by means of electrostatic attraction.

(ii) $E_1 = -13.6$ eV, $E_2 = \frac{-13.6}{2^2} = -3.4$

Required energy = $E_2 - E_1 = -3.4 + 13.6 =$ **10.2 eV.**

Example 17. *The half life period of a radioactive substance is 30 days. What is the time taken for (3/4)th of the origional mass to disintegrate?* **(CBSE 1994)**

Solution : Here, $N = N_o - \frac{3}{4}N_o = \frac{N_o}{4}$

Let the required time be t days. Therefore no. of half-lives in t days = $\frac{t}{30}$

$$\therefore N = N_o \left(\frac{1}{2}\right)^{n} \Rightarrow \frac{N_o}{4} = N_o \left(\frac{1}{2}\right)^{t/30}$$

$$\Rightarrow \left(\frac{1}{2}\right)^{2} = \left(\frac{1}{2}\right)^{t/30} \Rightarrow \frac{t}{30} = 2 \Rightarrow t = \textbf{60 days}$$

Example 18. *10 milligrams of a radioactive material of half-life period two years are kept in store for four years. How much of the material remains unchanged?*

Solution : N_o = Initial amount of radioactive material = 10 mg

T = half life = 2 years

$\therefore$ The disintegration constant $\lambda = \frac{0.693}{2}$ year^{-1}

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Let N be the amount of radioactive material left over after a time interval of 4 years. Then

$$N = 10\, e^{-\frac{0.693}{2}\times 4} = 10\, e^{-1.386} = \frac{10}{e^{1.386}} = \frac{10}{3.998} = \mathbf{2.501\ mg}$$

Example 19. *If the activity of a radioactive sample drops to 1/32 th of its initial value in 2 hrs, what is its half-life?*

Solution : We know that radioactivity of a sample drops to a value $\frac{1}{2^n}$ after n half lives. Given $n = 5$ ($\because 2^5 = 32$), Hence 5 half lives are equal to 2 hr. Therefore half-life of radioactive material $= \frac{2\times 60}{5} = 24$ **minutes.**

Example 20. *The half life of a radioactive substance is $1.192 \times 10^7 s$ against alpha decay. Calculate the decay rate for 3.18×10^{15} atoms of the substance.* **(CBSE 1994 Comptt.)**

Solution : The decay rate $\left(= \frac{dN}{dt}\right)$ is given by $\frac{dN}{dt} = -\lambda N$

Here $\lambda = 0.6931/\text{half life} = (0.6931)/(1.192 \times 10^7)\ s^{-1}$

Also $N = 3.18 \times 10^{15}$ atoms.

$\therefore$ Decay rate $= \frac{dN}{dt} = -\lambda N = -\frac{0.6931}{1.192} \times 10^{-7} \times 3.18 \times 10^{15} = \mathbf{-1.85 \times 10^8}$ **atoms/second**

Example 21. *The normal activity of living carbon-containing matter is found to be about 15 decays per minute for every grams of carbon. This activity arises from the small proportion of radioactive C^{14} present with the ordinary carbon isotope C^{12}. When the organism is dead, its interaction with the atmosphere (which maintains the above equilibrium activity) ceases and its activity begins to drop. From the known half-life (=5730 years) of ^{14}C and the measured activity, the age of the specimen can be approximately estimated. This is the principle of C^{14} dating used in archaeology. Suppose a specimen from Mohenjodaro gives an activity of 9 decays per minute per gram of carbon. Estimate the approximate age of the Indus-Valley civilization.*

Solution : The radioactive disintegrations are represented by the relation

$$N = N_o\, e^{-\lambda t}$$

Further, the activity is proporitonal to the number of radio active atoms so that

$\frac{dN_1}{dt} = \lambda N_1 = 15$ atoms per minute and $\frac{dN_2}{dt} = \lambda N_2 = 9$ atoms per minute

$\therefore \quad \frac{N_2}{N_1} = \frac{9}{15} = 0.6$

Hence, we have $e^{-\lambda t} = \frac{9}{15} = 0.6$

Also, $\lambda = \frac{\log_e 2}{T}$

Hence, $t = \frac{\log_e (5/3)}{\log_e 2} \times T = \frac{5730 \times 0.22193}{0.30103} = \mathbf{4223.2\ years}$

Example 22. *Obtain approximately the ratio of the nuclear radii of the gold isotope $^{137}_{79}Au$ and the silver isotope $^{107}_{47}Ag$. What is the approximate ratio of their nuclear mass densities? [Given : $r_o \approx 1.2 \times 10^{-15}\ m$]*

Solution : We know that $r = r_o\, A^{1/3}$ and $r_o = 1.2 \times 10^{-15}$ m

$\therefore \quad r_{Au} = r_o\,(137)^{1/3}$, and $r_{Ag} = r_0\,(107)^{1/3}$

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$$\frac{r_{Au}}{R_{Ag}} = \left(\frac{137}{107}\right)^{1/3} = 1.23$$

The ratio of their nuclear mass densities is of the order of one.

Example 23. *The three isotopes of neon : Ne^{20}, Ne^{21} Ne^{22} have respective abundance of 90.51%, 0.27% and 9.22%. The atomic masses of the three isotopes are 19.99u, 20.99 u and 21.99 u respectively. Obtain the average atomic mass of neon.*

Solution : The average atomic mass is the weighted mean of different isotopes. Therefore, average atomic mass of neon

$$= \frac{(19.99 \times 90.51) + (20.99 \times 0.27) + (21.99 \times 9.22)}{100}$$

$$= \frac{1809.29 + 5.67 + 202.75}{100} = \frac{2017.71}{100} = 20.18 \text{ u}$$

Example 24. *A nucleus X, initially at rest, undergoes, alpha decay according to the equation*

$$_{92}X^{A} \rightarrow {}_{Z}Y^{228} + \alpha$$

Find the values of A and Z in the above process.

Solution. We are given that $_{92}X^{A} \rightarrow {}_{Z}Y^{238} + \alpha$. Since α particle is nothing but $^{4}_{2}He$, we have

$A = 228 + 4 = 232$, and $92 = Z + 2$ or $Z = 90$

Example 25. *In the reaction $^{A}_{Z}X \rightarrow \alpha + Y$, give the atomic number and mass number of Y.*

Solution : Alpha particles are nothing but (positively charged) helium nuclei $\left(^{4}_{2}He\right)$. The atomic number and mass number of Y in the reaction, $^{A}_{Z}X \rightarrow \alpha + Y$, are therefore, (Z – 2) and (A – 4) respectively. Thus the complete reaction is

$$^{A}_{Z}X \rightarrow \alpha \left(= {}^{4}_{2}He\right) + {}^{A-4}_{Z-2}Y$$

Example 26. $^{235}_{92}U$ *decays successively to form* $^{234}_{90}Th$; $^{234}_{91}Pa$, $^{234}_{90}U$, $^{226}_{88}Ra$; $^{222}_{86}Rn$. *What are the radioactive radiations emitted in each decay process?* **(CBSE 1995 Comptt.)**

Solution :

$$^{235}_{92}U \rightarrow {}^{234}_{90}Th + {}^{1}_{1}H + {}^{0}_{+1}e$$

$$^{234}_{90}Th \rightarrow {}^{234}_{91}Pa + {}^{0}_{-1}e$$

$$^{234}_{91}Pa \rightarrow {}^{234}_{90}U + {}^{0}_{+1}e$$

$$^{234}_{90}U \rightarrow {}^{226}_{88}Pa + 2\,{}^{4}_{2}He + 2\,{}^{0}_{-1}e$$

$$^{226}_{88}Pa \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$$

Example 27. *A neutron strikes a $^{10}_{6}B$ nucleus with the subsequent emission of an α-particle. Write the corresponding nuclear reaction.* **(CBSE 1995 Comptt.)**

Solution : $^{10}_{6}B + {}^{1}_{0}n \rightarrow {}^{11}_{6}B \rightarrow {}^{4}_{2}He + {}^{7}_{4}Be$

Example 28. *A neutron is absorbed by a $^{6}_{3}Li$ nucleus with subsequent emission of an alpha particle. Write the corresponding nuclear reaction. Calculate the energy released in this reaction.*

[Give $m\left(^{6}_{3}Li\right) = 6.015126$ amu; $m\left(^{4}_{2}He\right) = 4.0026044$ amu $m\left(^{1}_{0}n\right) = 1.0086654$ amu; $m\left(^{3}_{1}H\right) = 3.016049$ amu] **(CBSE 1995)**

Solution. The corresponding nuclear reaction is

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$${}^{6}_{3}Li + {}^{1}_{0}n \rightarrow {}^{4}_{2}He + {}^{3}_{1}H + \text{energy}$$

Now sum of the masses of reactants = (6.015126 + 1.0086654) amu= 7.0237914 amu.
and sum of the mass of the resultants = (4.0026044 + 3.016049) amu= 7.0186534 amu
∴ Loss of mass, or mass defect = (7.0237914 – 7.0186534) amu= 0.0051380 amu.
Now 1 amu = 931 MeV
∴ Energy released = 0.005138 × 931 MeV= 4.78 MeV

Example 29. *Calculate the binding energy per nucleon of* ${}^{56}_{26}Fe$

[mass of ${}^{56}_{26}Fe$ *= 55.934939 amu, mass of proton = 1.007825 amu, mass of neutron = 1.008665 amu]*

Solution. For the nucleus ${}^{56}_{26}Fe$, we have number of protons = 26. **(CBSE 1993)**
number of neutrons = 56 – 26 = 30
∴ Mass defect = {[26 × 1.007825 + 30 × 1.008665] – [55.934939]} amu
= {[26.203450 + 30.259950] – [55.934939]} amu
= (56.463400 – 55.934939) amu = 0.528461 amu
Now 1 amu = 931 MeV
∴ Binding energy of ${}^{56}_{26}Fe$ = 0.528461 × 931 MeV = 491.997 MeV

∴ Binding energy per nucleon = $\frac{491.997}{56}$ MeV = 8.786 MeV = **8.8 MeV**

Example 30. *The sequence of the stepwise decay of radioactive nucleus is*

$$D \xrightarrow{\alpha} D_1 \xrightarrow{\beta} D_2 \xrightarrow{\alpha} D_3 \xrightarrow{\alpha} D_4$$

If the nucleon number and atomic number for D_2 *are respectively 176 and 71; what are the corresponding values for D and* D_4 *nuclei. Justify your answer.?*

(CBSE 1998)

Solution: Let the atomic number and nucleon number of D be Z and A respectively. Then we know that the emission of an α-particle from an atom will change it into a new atom whose atomic number is reduced by 2 and the nucleon number is reduced by 4.

Also, on β-emission, the atomic number increases by 1 and the nucleon number remains the same. Hence, the given equation can be written as,

$${}^{A}_{Z}D \xrightarrow{\alpha} {}^{A-4}_{Z-2}D_1 \xrightarrow{\beta} {}^{A-4}_{Z-1}D_2 \xrightarrow{\alpha} {}^{A-8}_{Z-3}D_3 \xrightarrow{\alpha} {}^{A-12}_{Z-5}D_4$$

Now, A – 4 = 176 ⇒ A = 180 and Z – 1 = 71 ⇒ Z = 72.
Also, for D_4 nuclei, atomic number = 72 – 5 = 67, nucleon number = 180 – 12 = 168.

Example 31. *A radioactive isotope decay according to the sequence*

$$D \xrightarrow{{}^{1}_{0}n} D_1 \xrightarrow{\alpha} D_2$$

If the mass number and atomic number of D_2 *are 176 and 71 respectively, find the mass number and atomic number of D. Amongst D,* D_1 *and* D_2 *do we have any isobars or isotopes?*

(CBSE 1998, 1999)

Solution: ${}^{A}_{Z}D \xrightarrow{{}^{1}_{0}n} {}^{A}_{Z+1}D_1 \xrightarrow{\alpha} {}^{A-4}_{Z-1}D_2$

∴ A – 4 = 176 ⇒ A = 180
Z – 1 = 71 ⇒ Z = 72.
D and D_1 are isobars.

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Example 32. *The half-life of a radioactive substance is 30 sec. Calculate:*
(i) The decay constant.
(ii) Time taken for the sample to decay to 3/4 th of its initial value. **(CBSE 1999)**

Solution: $t_{½} = 30$ sec.

(i) $\lambda = \dfrac{0.693}{t_{½}} = \dfrac{0.6983}{30} = \mathbf{0.0231\ sec^{-1}}$

(ii) Number of atoms disintegrated $= \dfrac{3}{4} N_o$

Number of atoms left, $N = N_o - \dfrac{3}{4} N_o = \dfrac{1}{4} N_o$

Number of half-lives in t seconds, $n = \dfrac{t}{30}$

$\therefore N = N_0 \left(\dfrac{1}{2}\right)^n \Rightarrow \dfrac{N_0}{4} = N_0 \left(\dfrac{1}{2}\right)^{t/30} \Rightarrow 2^{t/30} = 2^2 \Rightarrow \dfrac{t}{30} = 2 \Rightarrow t = 60$ seconds

Hence, the required time is 60 seconds.

Example 33. *Calculate binding energy per nucleon of* $^{209}_{83}Bi$. *Given* $m\left(^{209}_{83}Bi\right) = 208.980388$ *amu, m (proton) = 1.009825 amu, m (neutron) = 1.008665 amu* **(CBSE 1995)**

Solution : $^{209}_{83}$Bi nucleus consists of 83 proton and 126 neutrons. The sum of masses of the nucleons (M_1) is

$M_1 = 83 \times 1.009825 + 126 \times 1.008665$

$= 83.815475 + 127.09175 = 210.90727$ amu

The mass defect (Δm) is

$\Delta m = 210.90727 - 208.980388 = 1.926885$ amu

$\therefore$ Binding Energy of $^{209}_{83}$Bi $= 1.926885 \times 931$ MeV $= 1793.9299$ MeV

The binding energy per nucleon $= \dfrac{1793{\cdot}9299}{209} = \mathbf{8.5834\ MeV}$

Example 34. *The binding energy per nucleon for* C^{12} *is 7.68 MeV and that for* C^{13} *is 7.47 MeV. Calculate the energy required to remove a neutron from* C^{13}.

Solution : Binding energy/nucleon for $C^{12} = 7.68$ MeV and number of nucleons in C^{12} nucleus is 12

$\therefore$ Total binding energy of C^{12} nucleus $= 7.68 \times 12 = 92.16$ MeV

Binding energy/nucleon for $C^{13} = 7.47$ MeV and number of nucleons in C^{13} nucleus = 13.

Total binding energy of C^{13} nucleus $= 7.47 \times 13 = 97.11$ MeV

Therefore, energy required to remove one neutron from C^{13} nucleus

$= (97.11 - 92.16)$ MeV $= \mathbf{4.95\ MeV}$

Example 58. *Assuming that the energy released by the fission of a single uranium atom is 200 MeV., calculate the number of fissions per second required to produce 1 watt of power.*

Solution : Energy per fission $= 200$ MeV $= 2 \times 10^8 \times 1.6 \times 10^{-19}$ joule

$= 3.2 \times 10^{-11}$ joule $= 3.2 \times 10^{-11}$ watt second

$\therefore$ Number of fissions required per second

$= \dfrac{1}{3.2 \times 10^{-11}}$

$= \mathbf{3.125 \times 10^{10}}$ **fissions.**

Example 36. *Calculate the energy released by fission of 1 g of* U^{235} *in kWh. Energy per fission is 200 MeV.*

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$\therefore$ 1 gram of U^{235} contain $\frac{6.02 \times 10^{23}}{235}$ atoms

Energy per fission = 200 MeV = 2×10^8 eV = $2 \times 10^8 \times 1.6 \times 10^{-19}$ J = 3.2×10^{-11} J

$\therefore$ Total energy = $\frac{6.02 \times 10^{23}}{235} \times 3.2 \times 10^{-11}$ J = $\frac{6.02 \times 3.2}{235} \times 10^{12}$ joule = 8.2×10^{10} J

Now 3.6×10^6 J = 1 kWh. Hence 1 J = $\frac{1}{3.6 \times 10^6}$ kWh

$\therefore$ Energy in kWh = $\frac{8.2 \times 10^{10}}{3.6 \times 10^6}$ kWh = $\mathbf{2.28 \times 10^4}$ **kWh**

Example 37. *Calculate the energy liberated when a single helium nucleus is formed by the fusion of two deuterium nuclei. Given, mass of* ${}_1^2H = 2.01478$ *a.m.u., mass of* ${}_2^4He = 4.00388$ *a.m.u.*

Solution : The reaction is represented by ${}_1^2H + {}_1^2H \rightarrow {}_2^4He +$ energy

Mass of 2 deuterium atoms = $2 \times 2.01478 = 4.02956$ a.m.u.

Mass of the helium atom = 4.00388 a.m.u.

$\therefore$ Mass defect, $\Delta m = (4.02956 - 4.00388)$ a.m.u. = 0.02568 a.m.u.

Energy released = 0.02568×931 MeV = 23.90808 MeV $\approx$ **24 MeV**

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UNIT XII

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SOLIDS AND SEMI-CONDUCTOR DEVICES

CBSE SYLLABUS CONTENTS

Energy bands in solids, conductors, insulators and semi-conductors, pn junction, diodes, solar cells, junction transistor, diode as rectifier, transistor as an amplifier and oscillator, logic gates and combination of gates - NAND and NOR.

No. of periods allotted : 18 out of 168

No. of marks allotted : 8 out of 70.

BASIC FACTS AND FORMULAE

Solids are divided into two main categories : (i) crystalline and (ii) amorphous. A crystalline solid has its atoms arranged in a regular, repeated pattern. There exists a long range order. On the other hand, amorphous solids lack regularity in the arrangement of atoms or molecules.

1. Bonding in Solids

The atoms in solids are held together by different type of bonds. The important bonds are :

(i) *Ionic bond:* It is provided by the electrostatic force of attraction between two oppositely charged ions, the outer shells of the ions are complete and, therefore ions are stable. Ionic bond is quite strong. Crystals having ionic bonds, (i) have high melting point, (ii) are hard and brittle, (iii) are poor conductor of electricity.

(ii) *Covalent bond:* These bonds arise due to sharing of electrons by the constituent atoms. Covalent bonds are *less stronger* than ionic bonds. Crystals having covalent bonds:

(i) Are hard but not brittle, (ii) have melting point lower than those of ionic crystals, (iii) are perfect insulators at absolute zero. The electrical conductivity rises with rise of temperature.

(iii) *Metallic bond:* A metal crystal consists of rows of positive ions embedded in a almost uniform distribution of free electrons. The free electrons are the valence electrons of atoms constituting the crystal. Crystals having metallic bonding have following important properties: (i) Melting point is lower than those of ionic or covalent bonds, (ii) can be easily deformed, (iii) electrical and thermal conductivity is high, (iv) metals, though opaque, have their characteristic luster.

(4) *Van der Waal's bond:* The weak bonding provided between atoms and molecules due to weak attractive forces, are referred to as Van der Waal's forces. Crystals having Van der Waal's bond :

(i) Have small mechanical strength, (ii) are soft and can be easily compressed and deformed, (iii) have low melting point, (iv) are poor conductors of electricity.

2. Band Theory of Solids

A solid consists of a large number of atoms closely packed. The energy of a solid is obtained by superimposition of large number ($N \sim 10^{23}$) of energy levels of each atoms constituting the solid. Superimposition of large number of energy levels results in the formation of *energy bands.* In general, between two permitted energy bands, there exists region where no permitted energy level exists. This forbidden region is referred to as *energy gap.*

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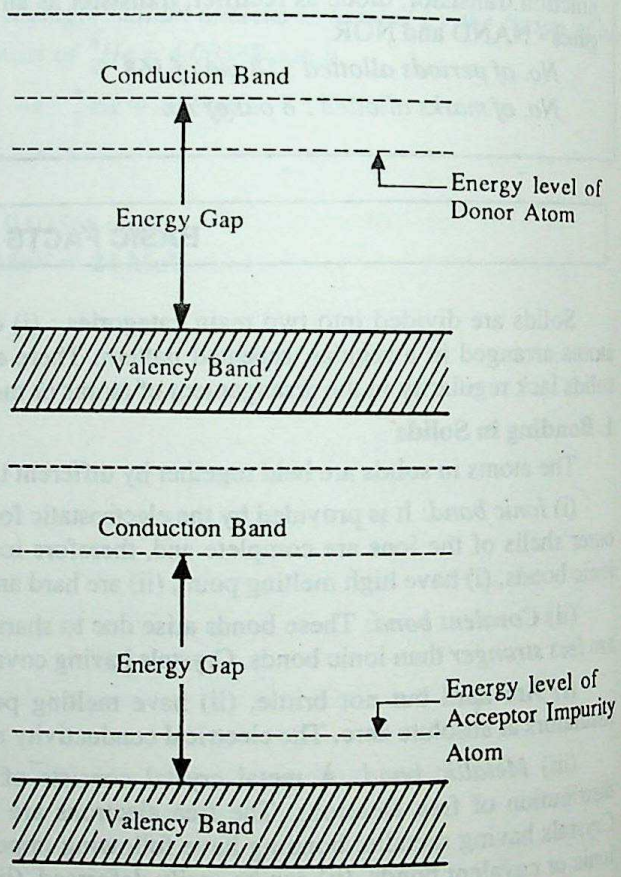
The energy band corresponding to valence electrons is called the *valence band.* The band corresponding to electrons that can move freely is known as *conduction band.* In general, there is energy gap between valence and conduction band.

Classification of solids into (i) *conductors,* (ii) *insulators,* and (iii) *semiconductors,* is in terms of energy gap between valence and conduction bands. In conductors the valence and conduction bands overlap, *i.e.,* there is no energy gap. In insulators the energy gap between valence and conduction band is very large. In semiconductors the energy gap is small (1 – 2 eV). At absolute zero all semiconductors are perfect insulators. Conductivity of semiconductors increases with rise in temperature. Pure semiconductors are known as *intrinsic semiconductors.* Addition of appropriate impurities in a pure semiconductor produces *extrinsic semiconductors.*

3. The n - and p-type Semiconductors

(i) n-type semiconductor is obtained when a *pentavalent* impurity atom, like phosphorus, antimony or arsenic is added to a pure silicon or germanium semiconductor. Each impurity atom shares four electrons with neighbouring atom. The fifth electron is not attached to any atom and remains free. In other words, each impurity atom produces one free electron without producing a hole. The number of free electrons is much more than number of holes. Electrons are known as *majority charge carriers* and the holes are the *minority charge carriers.* The pentavalent impurity atom is known as a *donor type* impurity atom.

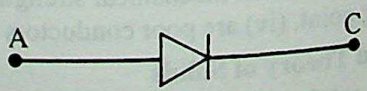
Fig. alongside shows the energy band diagram of a n-type semiconductor.



(ii) *p-type semiconductor* is obtained by adding a *trivalent* impurity atom, like aluminium, boron, gallium, indium to pure semiconductor. There are three electrons in the outermost orbit of impurity atom. These form covalent bonds with three neighbouring atom. However, there is deficiency of electron and the fourth covalent bond is not complete. This deficiency of electron is known as a *hole.* A hole behaves as a positive charge. Each impurity atom produces a hole without producing a free electron. The majority charge carriers are positively charged holes. The electrons are the minority charge carriers. Fig. alongside shows the energy band diagram of a p-type semiconductor.

4. The Junction Diode

A junction diode is obtained by growing a single crystal of silicon or germanium which is doped with say n-type impurity during first half of its growth and p-type impurity during the second half. At the junction the holes from p-region diffuse into n-region and vice-versa. This results in the development of a barrier potential and further movement of charge carriers stops. The logic symbol of a junction diode is shown.



Symbol of junction diode.

5. The Forward and Reverse Bias

In the absence of any external applied field; there is no net current flow across the junction. If the n-region is connected to the negative and the p-region to the positive of an external potential source, both electrons and

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holes are pushed towards the junction, resulting in the flow of a current. This is shown in fig. below. The p-n junction is *forward biased*. Under forward bias conditions, there is a current flow across the junction.

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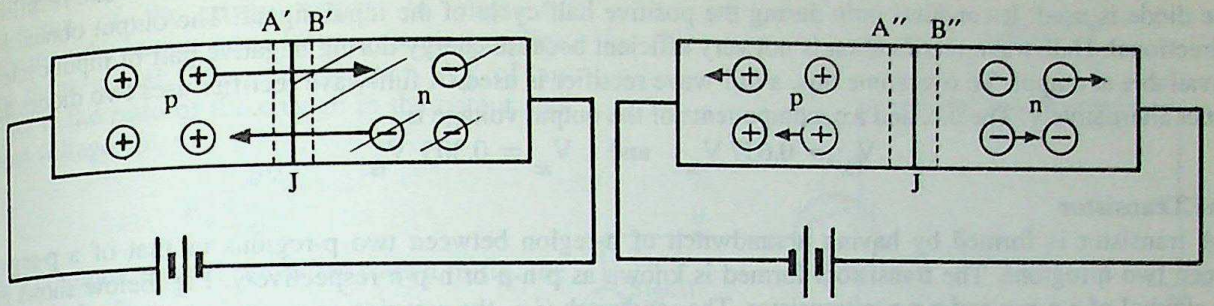


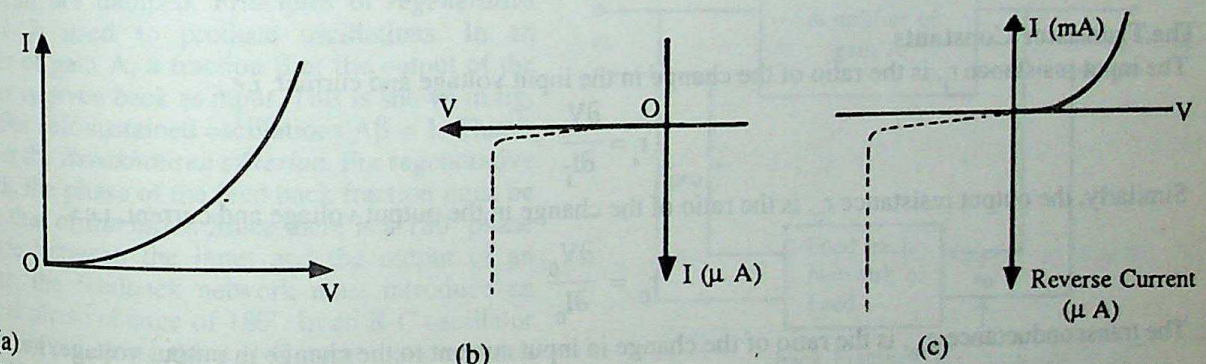
Forward Bias Reverse Bias.

If the n-region is connected to the positive and the p-region to the negative of a battery; the majority carriers (both electrons and holes) are pulled away from the junction. This results in a increased barrier potential and there is no flow of charge carriers across the junction. The junction is *reverse biased*. This is shown in fig. below. There is no flow of current when junction diode is reverse biased.

Junction diode has a unidirectional flow of current.

6. The characteristic Curves of a Junction Diode

The relation between applied plate potential, known as the plate potential V_p; and current I_p is the characteristic curve. The characteristic curves of a junction diode are *non-linear*. Under reverse bias conditions current is practically zero if applied potential is not very high. However, on increasing reverse potential beyond a limit, a large current flows. The junction is said to have broken down. Fig. below (a), (b) and (c) give the forward biased, the reverse biased and the complete characteristic curves respectively of a junction diode.



(a) (b) (c)

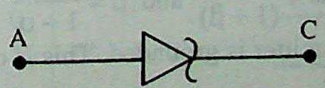
The ratio of change in applied voltage to the change in current is the resistance of the diode. In symbols

$$r = \frac{\partial V}{\partial I}.$$

Under forward bias, the resistance of junction diode is quite low (of the order of a few ohms). However, under reverse biasing, the resistance of a junction diode is high (of the order of a few kilo-ohms)

7. The Zener Diode

Under reverse bias conditions when the applied voltage is such as to cause a large reverse current we say that Zener breakdown has occurred. Fig below shows the ionic symbol of a Zener diode. The breakdown is due to either of the following two processes : (i) Zener breakdown. (ii) Avalanche breakdown. In a Zener diode, the current is practically independent of the applied voltage. This property of Zener diode is used to obtain *voltage regulation.*



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8. The Half and Full-wave Rectifier

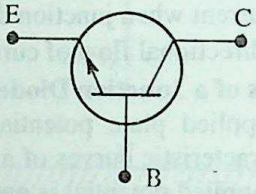
Due to unidirectional current characteristics, a junction diode is used as a rectifier. In a half-wave rectifier a single diode is used. It conducts only during the positive half cycle of the input signal. The output obtained is unidirectional. Half-wave rectification is not very efficient because energy during negative half of input cycle is not available at output. To overcome this, a full-wave rectifier is used. A full-wave rectifier uses two diodes that conduct alternatively. The d.c. and a.c. components of the output voltage is

$$V_{dc} = 0.637\, V_m \quad \text{and} \quad V_{ac} = 0.305\, V_m$$

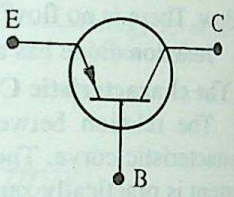
9. The Transistor

A transistor is formed by having a sandwitch of n-region between two p-regions or that of a p-region between two n-regions. The transistors formed is known as p-n-p or n-p-n respectively. Fig. below shows the logic symbol of a n-p-n and a p-n-p transistor. The sandwitch (*i.e.*, the n-region or p-region in the p-n-p or n-p-n transistor) is lightly doped and is known as base. The n-region in n-p-n transistors that supplied majority charge carriers, (*i.e.*, electrons) is known as emitter and the *n*-region that collects theses electrons is known as the collector. *Emitter in all transistors is always forward biased, whereas the collector is always reverse biased.* Emitter and collector in a transistor cannot be interchanged.

In a n-p-n transistor, say when the emitter is forward biased, the electrons are pushed towards the base. Since base region is very thin and lightly doped, most of the electrons are able to pass through and are further attracted towards the reverse biased collector. Since a few carriers always undergo recombination in base, the collector current, I_c; is always less than the emitter current I_E. In symbols $I_E = I_C + I_B$, where I_B is the base current.



The n-p-n Transistor



The p-n-p Transistor

10. The Transistor Constants

The input resistance r_i, is the ratio of the change in the input voltage and current, *i.e.*,

$$r_i = \frac{\partial V_i}{\partial I_i}$$

Similarly, the output resistance r_o, is the ratio of the change in the output voltage and current, i.e.,

$$r_0 = \frac{\partial V_0}{\partial I_0}$$

The transconductance g_m, is the ratio of the change in input current to the change in output voltage, i.e.,

$$\delta_m = \frac{\partial I_i}{\partial V_0}.$$

The current gain α; is the ratio of the change in the collector current to the change in emitter current and is always less than unity. The current gain β, is the ratio of the change in collector current to the change in the base current. Usually β is a large number of the order of 100 or more.

The input resistance of a transistor is usually low, whereas the output resistance is high. The name transistor, itself originates from transfer of resistance.

In common-base configuration, base is common to both emitter and collector and is at ground potential. The current gains α and β are related to one another via the relations ;

$$\alpha = \frac{\beta}{(1+\beta)} \text{ and } \beta = \frac{\alpha}{1-\alpha}$$

In common emitter configuration the emitter is grounded. This is one of the most commonly used transistor configuration.

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11. Amplifier

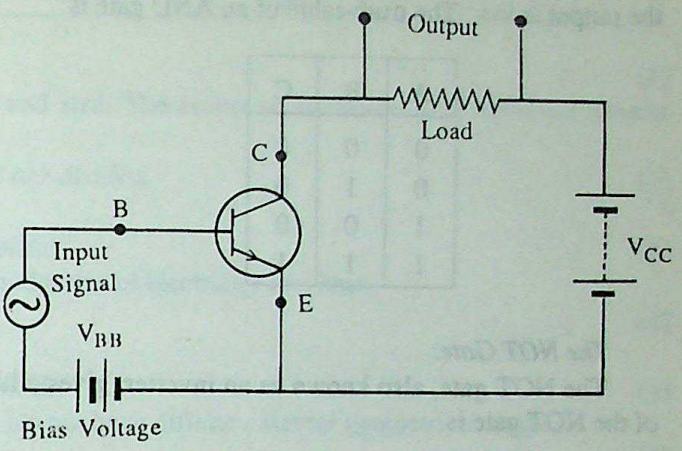
An amplifier is a device that enhances a desired characteristic of the given signal. In class A, amplification the output wave form is an exact replica of the input signal. The voltage gain A_v, of an amplifier is the ratio of the change in the output and the input voltage, *i.e.*,

$$A_v = \frac{\partial V_0}{\partial V_i}$$

In a common emitter amplifier shown in fig. the voltage gain A_v. is

$$A_v = -B_{ac}\left(\frac{R_L}{r_i}\right)$$

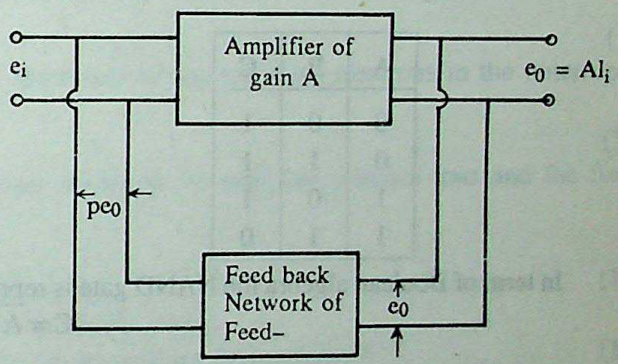
The power gain A_p, is $A_p = B_{ac} \cdot A_v$



The gain of an amplifier cannot be increased indefinitely by increasing value of load resistance R_L only. Because beyond a value of R_L, V_{BE} decreases and it becomes less than V_{BB}. Both emitter and collector are forward biased and transistor operates in the *saturation region.* The transistor cannot be used as an amplifier in the saturation region because there is no change in the output current and consequently no change in the output voltage, when input changes. For a transistor to work as an amplifier $\beta I_B \geq I_C$.

Oscillator

An oscillator is a device to produce vibrations of constant amplitude and frequency. The basic oscillator circuit is an L-C circuit. However, oscillations of an L-C circuit are damped. Principles of *regenerative feedback* is used to produce oscillations. In an amplifier of gain A, a fraction β of the output of the amplifier is given back as input. This is shown in fig. below. For self-sustained oscillations $A\beta = 1$. This is known as the *Breakhausen criterion.* For regenerative feedback, the phase of the feed back fraction must be same as that of the input. Since there is a 180° phase difference between the input and the output of an amplifier, the feedback network must introduce an additional phase change of 180°. In an R-C oscillator this is achieved using three R-C combinations, each introducing a phase change of 60°.



13. Logic Gate

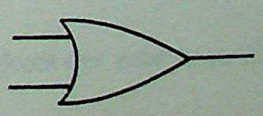
A *logic gate* is a circuit which has one or more than one inputs but only one output. Pulses are used in digital electronics. The positive value (or high value) is used to represent binary number 1 and the low value (or zero value) to represent binary number 0. This is known as positive logic.

The OR Gate:

The OR gate is the logic circuit using two diodes. It has two inputs A and B and one output C. When either one or both of the inputs are high, the output is high. If both inputs are low, the output is also low. The truth-table of an OR gate is

A	B	C
0	0	0
0	1	1
1	0	1
1	1	1

The logic-symbol of an OR gate is.



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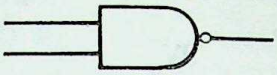
The AND Gate:

The AND gate gives an output, that is, high when both inputs are high. If both or either of the inputs is low, the output is low. The truth-table of an AND gate is

A	B	C
0	0	0
0	1	0
1	0	0
1	1	1

The logic-symbol of an AND gate is.

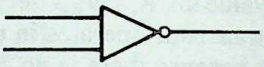


The NOT Gate:

The NOT gate, also known as an inverter, gives a high output for low input and *vice-versa.* The truth-table of the NOT gate is

Input	Output
0	1
1	0

The logic-symbol of a NOT gate is

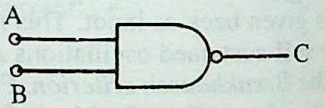


The NAND Gate:

The NAND gate is a combination of an AND and a NOT gate. The truth-table of a NAND gate is

A	B	C
0	0	1
0	1	1
1	0	1
1	1	0

The logic -symbol of a NAND gate is



In term of Boolean algebra the NAND gate is represented by

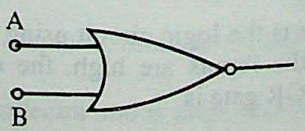
$$C = \overline{A \cdot B} \text{ or } \overline{AB}$$

The NOR Gate:

The NOR gate is a combination of an OR and a NOT gate. The truth-table of NOR gate is

A	B	C
0	0	1
0	1	0
1	0	0
1	1	0

The logic-symbol of NOR gate is



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SUBJECTIVE QUESTIONS ON UNIT – XII

Q.1. *What is a solid?* (1)

Ans. A solid is material having a definite shape and size. The atoms or molecules in a solid are closely packed and arranged in a regular pattern.

Q.2. *Name the two broad classes into which solids are divided.* (1)

Ans. Crystalline and amorphous.

Q.3. *List two important properties of crystalline solids.* (1)

Ans. (i) High and sharp melting point. (ii) Poor conductors of electricity and heat.

Q.4. *Name two crystalline solids.* (1)

Ans. Calcite, rock salt.

Q.5. *List two important properties of amorphous solids.* (1)

Ans. (i) Do not possess a sharp melting point. (ii) Do not have difinite external geometrical shape.

Q.6. *Name two amorphous solids.* (1)

Ans. (i) Glass, (ii) Pitch.

Q.7. *Distinguish between crystalline and amorphous solids.* (2)

Ans. When amorphous solids are heated, they start softening gradually before melting. In other words, amorphous solids do not have a sharply defined melting point.

When a crystalline solid is heated, it does not soften before melting. It possess a sharp melting point.

Q.8. *What is ionic bonding?* (1)

Ans. Ionic bonding is due to electrostatic attraction between two oppositely charged ions. The outermost shell of ions is complete, therefore, ions are stable.

Q.9. *What is covalent bonding?* (1)

Ans. In covalent bonding, the neighbouring atoms share one or more of their electrons in the outermost orbit.

Q.10. *What are metallic bonds?* (1)

Ans. The metallic bonding is due to the electrostatic attraction between the positive ions and the free electrons.

Metallic bond is a weak bond.

Q.11. *Name the type of bonding in insulators and conductors.* (1)

Ans. Insulators have ionic bonding. Conductors have metallic bonding.

Q.12. *A material having covalent bonding is insulator, semiconductor or conductor?* (1)

Ans. Semiconductor.

Q.13. *Name the type of bonding in (i) diamond (ii) germanium.* (1)

Ans. (i) Covalent (ii) Covalent

Q.14. *What is an energy band in solids?* (1)

Ans. An energy band consists of a large number of discrete but closely packed energy levels.

Q.15. *What is meant by the valence band?* (1)

Ans. The valency electrons in a solid possess energy in a certain range. This range of energy constitutes the valency band.

Q.16. *What is meant by the conduction band?* (1)

Ans. The conduction electrons in a solid can possess energy in a definite range. This range of energy constitutes the conduction band.

Q.17. *What is energy gap?* (1)

Ans. The valency and conduction band, in general; separated from one another by a region in which there is no permitted energy state. This region is known as the energy gap.

Q.18. *What is Fermi level?* (1)

Ans. The highest occupied energy level, in conduction band, at absolute zero of temperature is known as the Fermi-level.

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Q.19. *Define the term "forbidden gap" for a solid.* (2)

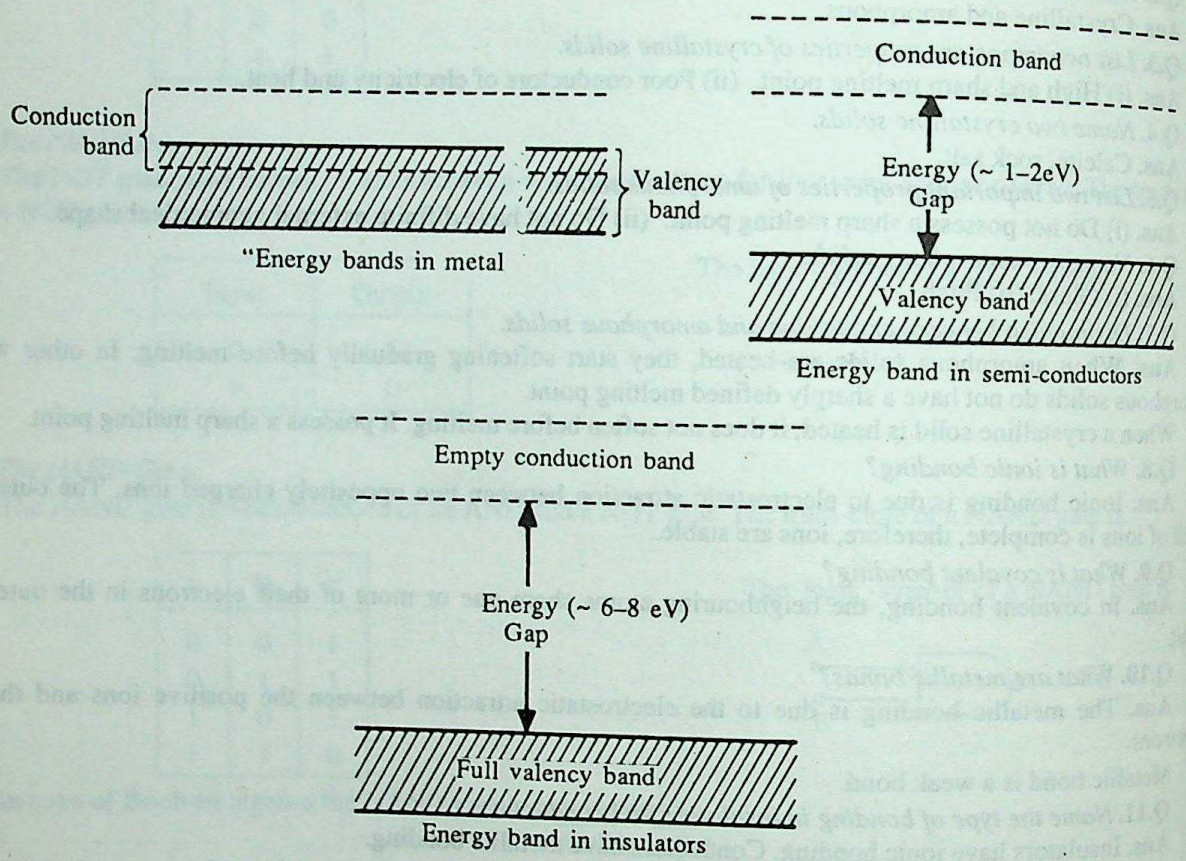
Ans. In between the valency and conduction band, there is a region in which no electron can be present. In other words, there is no permitted energy state in this region. This region is known as the forbidden region.

Q.20. *What is the order of the forbidden energy gap in conductors and insulators?* (1)

Ans. In conductors there is no forbidden region. In insulators the forbidden region is about 6 – 8 eV.

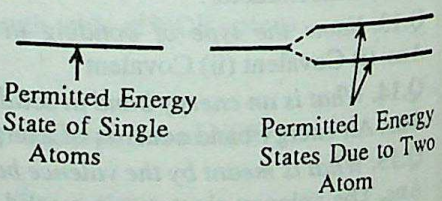
Q.21. *Draw a diagram showing comparative energy band models for metals, semiconductor and insulators.* (2)

Ans.

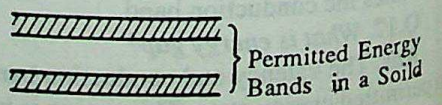


Q.22. *Give an account of the formation of energy bands in solids. What is their significance?*

Ans. According to Bohr's theory, the electrons in an atom have some well defined energy states known as *energy levels.* An electron in an atom can be present in one of these permitted energy states only. However, when an other atom is brought near the first, their outermost electrons interact with one another. Due to this interaction the permitted energy states of these outermost electrons (usually known as valency electrons) are slightly altered. In other words, the permitted energy state of single electron breaks up into two nearby permitted states as shown in fig. (a) alongside. This interaction, however, leaves the inner shells of the atoms uneffected. Due to the interaction of atoms the energy levels of the outer most shells are slightly altered. For two atoms one permitted energy state breaks up into two nearby permitted states. The number of these nearby permitted states is same as the number of interacting atoms. In a crystal, there are very large number of interacting atoms (~ 10^{23} atoms).



(a)



(b)

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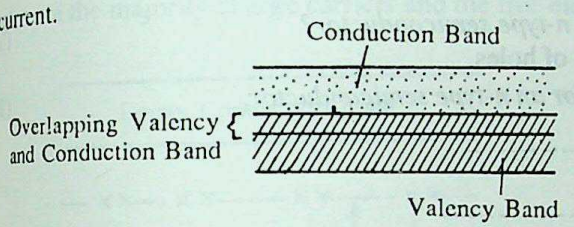
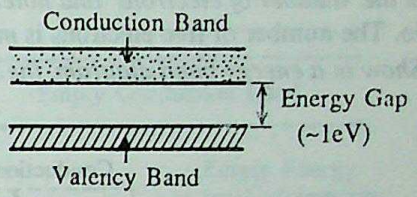
Thus, each permitted level of the electron in outermost shell splits up into nearby 10^{23} levels. Such a large number of levels in a small energy range of just a few electron volt are so close to each other as to form a band of continuous energy distribution. This is shown in fig. (b) below. Depending on the composition of a crystal the permitted bands may overlap or may be well separated from one another. If the energy bands are well separated from one another, the gap between them where there is no permitted energy state is known as *energy gap* or the *forbidden band.*

Q.23. *Distinguish between conductors, semiconductors and insulators in terms of band theory of solids.* **(3)**

Ans. (i) ***Conductors :*** In conductors the valency band is not full and there is an overlapping between the valency and the conduction band. Since, valency band itself is not full, the electrons can move about freely in valency band. Very small energy is needed to move electrons from the valency to the overlapping conduction band. This energy is provided by the externally applied electric field. It is these moving electrons that constitute current.

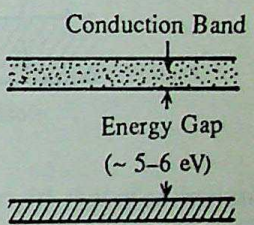


Energy bonds in conductors



Energy bonds in semi-conductor

(ii) ***Semiconductor :*** In semiconductor there is a small gap (about 1.1 eV) between the valency and the conduction band. At absolute zero, the valency band is full and the conduction band is empty. As energy gap is not large at room temperature due to random thermal energies some of the electrons jump from the valency to the conduction band. The electrons in conduction band move when an external electric field is applied and constitute the current.



Energy bonds in insulators

(iii) ***Insulators :*** In insulators the valency band is completely full. There is a large energy gap between the valency and conduction band. The energy gap is of the order of 6 eV. The conduction band is empty. Due to large energy gap electrons cannot move from the full valency band to empty conduction band. Since, there is no movement of electrons, there is no current.

Q.24. *What is the conductivity of a semiconductor at absolute zero?* **(1)**

Ans. At absolute zero of temperature the conductivity of a semiconductor is zero.

Q.25. *How does the conductivity of a semi conductor vary with increase in temperature?* **(CBSE 1998) (1)**

Ans. Conductivity increases as temperature increases.

Q.26. *What are intrinsic semiconductors?* **(1)**

Ans. A semiconductor without any impurities is known as an intrinsic semiconductor.

Q.27. *Name two intrinsic semiconductors.* **(1)**

Ans. *Silicon* and *germanium* are two intrinsic semiconductors.

Q.28. *What are charge carriers in an intrinsic semiconductor?* **(1)**

Ans. Free electrons and holes.

Q.29. *What is a hole? How do we use the "hole" idea to discuss the electrical behaviour of a semi-conductor?* **(3)**

Ans. When a covalent bond is broken either by knocking out the electron participating in it or there is a deficiency of an electron in the atom participating in covalent bond; we say a hole is created. A hole behaves as a positive charge. A hole can move by stealing an electron from a neighbouring atom. The location of hole moves to the atom losing electron. When an external p.d. is applied, the location of holes in solid change. This is equivalent to a positive charge moving under applied p.d. This constitutes a current. This current is due to motion of holes. Therefore, holes play an important role in the electrical behaviour of semiconductors.

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Q.30. *Is the number of electrons greater than, less than or equal to the number of "holes" in an intrinsic semiconductor?*

Ans. In an intrinsic semiconductor the number of free electrons and holes is same. (1)

Q.31. *What is doping of a semiconductor?*

Ans. The process of adding a desired impurity atom to a pure semiconductor is known as doping. (1)

Q.32. *What is meant by an n-type semiconductor?*

Ans. If a *penta-valent* impurity atom is added to a pure semiconductor we obtain an n-type semi-conductor. (1)

Q.33. *What are majority and minority charge carriers in an n-type semi conductor?*

Ans. The majority charge carriers are electrons. The minority charge carriers are holes. (1)

Q.34. *Name some of the impurity atoms needed to get an n-type semiconductor.*

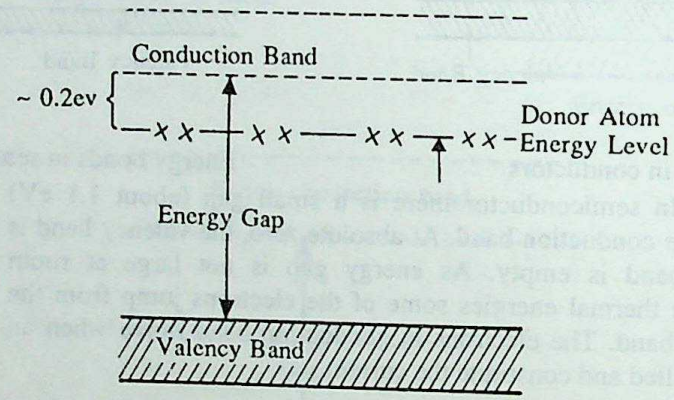
Ans. (i) Phosphorus (ii) Antimony (1)

Q.35. *Is the number of electrons and holes equal in an n-type semiconductor?*

Ans. No. The number of free electrons is *more* than that of holes. (1)

Q.36. *Show in a energy band diagram, the donor level for an n-type semiconductor.* (2)

Ans.



Q.37. *What is a p-type semiconductor?* (1)

Ans. If a *trivalent* impurity atom is added to a pure semiconductor; a p-type semiconductor is obtained.

Q.38. *Name the majority and minority charge carriers in a p-type semiconductor.* (1)

Ans. Majority charge carriers are holes. Minority charge carriers are free electrons.

Q.39. *Is the number of electrons and holes equal in a p-type semi conductor?* (1)

Ans. No. The number of holes is more than the number of free electrons.

Q.40. *Name two dopants used to produce a p-type semiconductor.* (1)

Ans. (i) Boron (ii) Gallium.

Q.41. *What is a donor impurity atom?* (1)

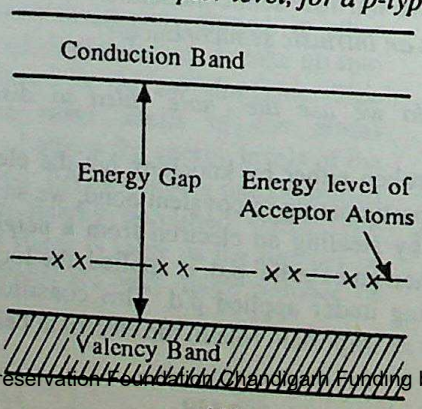
Ans. A pentavalent impurity atom is known as a donor impurity atom.

Q.42. *What is an acceptor impurity atom?* (1)

Ans. A trivalent impurity atom is known as an acceptor impurity atom.

Q.43. *Draw in a energy band diagram, the acceptor level, for a p-type semiconductor.* (2)

Ans.



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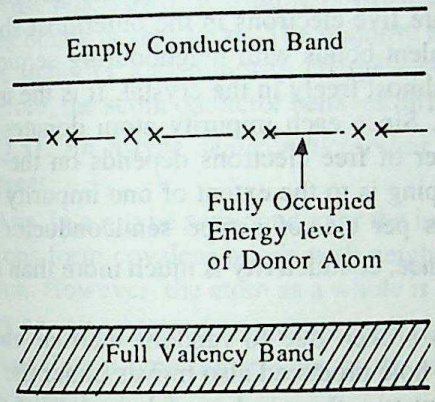
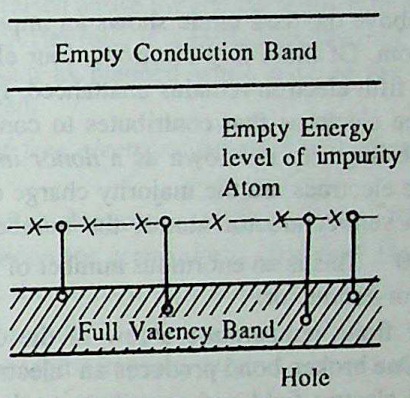
Q.44. *Discuss the electrical conductivity of both types of extrinsic semiconductors in terms of the energy band picture.* **(3)**

Ans. Fig. (a) below shows the energy band diagram of a n-type semiconductor. The valency band is fully occupied and conductor band is empty. The energy level of impurity atom is very near to empty conduction band. The electrons can easily jump from this energy level to empty conduction band. The electron in conduction band is a free electron. The production of a free electron is not accompanied by production of a hole. Therefore, majority charge carriers are free electrons. The holes are minority charge carriers.

Fig. (b) below shows the energy band diagram of a p-type semiconductor. The empty energy level of impurity atom is very close to the valency band. At any finite temperature, electrons can easily jump from valency band to this empty energy level. This results in the production of a *hole*. Note that creation of hole is not accompanied by formation of a free electron. Therefore, number of holes is more than that of free electrons. The holes are the majority charge carriers and the free electrons are minority charge carriers.





Q.45. *Compare the energy band picture of the two types of extrinsic semiconductors with that of an intrinsic semiconductor.* **(2)**

Ans.

S. No.	Intrinsic semiconductor	Extrinsic semiconductor
1.	There is no permitted energy state in between the valency and the conduction band.	There is a permitted energy state of impurity atom in between the valency and the conduction band.
2.	Number of free electrons and holes is same.	Number of free electrons and holes is not same. In a p-type semiconductor number of holes is more than the number of free electrons.
3.	There are no majority or minority charge carriers.	There are majority and minority charge carriers.
4.	Electrical conductivity is low.	Electrical conductivity is more in comparison to a pure semiconductor.

Q.46. *What changes are expected in the majority to minority charge carriers ratio as the temperature of an extrinsic semiconductor is raised?* **(2)**

Ans. As temperature rises the number of minority charge carriers increases. However, the number of majority charge carriers remain same. Therefore, the ratio of majority to minority charge carriers decreases as temperature is raised.

Q.47. *Explain how an intrinsic semiconductor can be converted into (i) n-type and (ii) p-type semiconductor. Give one example of each and their energy band diagrams.* **(3)**

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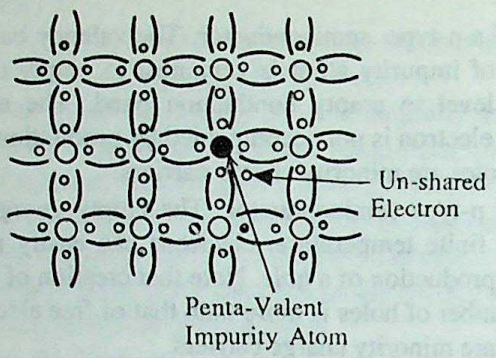
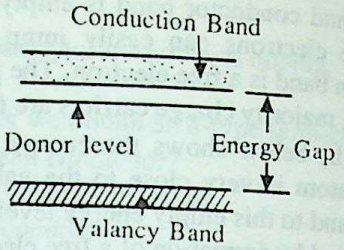
Ans. *n-type semiconductor:*

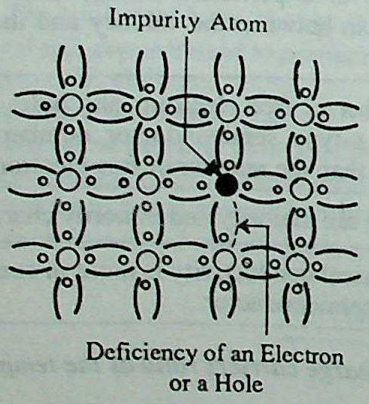


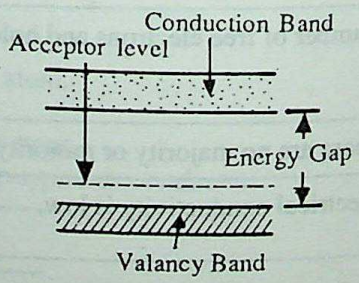


A n-type semiconductor is obtained by adding a *penta-valent* impurity to an intrinsic semiconductor. In fig. (a) above the dark circle shows an impurity atom. There are five electrons in the outermost shell of the impurity atom. Of these five electrons, four electrons share covalent bonds with neighbouring semiconductor atoms. The fifth electron remains unattahced. It can move about almost freely in the crystal. It is the movement of these free electrons that contributes to conduction of current. Since each impurity atom donates one free electron, the impurity is known as a *donor impurity.* The number of free electrons depends on the extent of doping. The electrons are the majority charge carriers. If the dopping is to the extent of one impurity atom per one million semiconductor atoms, the number of free electrons per c.c. of n-type semiconductor is about $10^{23}/10^{6} \sim 10^{17}$. This is an enormous number of free eleectrons. Hence, conductivity is much more than that of an intrinsic semi-conductor.

At any finite temperature a few of the covalent bonds are broken due to random thermal energies of electrons. One broken bond produces an 'electron–hole' pair. The hole produced also moves under the action of the applied electric field and contribute to the conductivity. However, the number of holes is very small as compared to the number of electrons. Therefore, *holes* are known as minority charge carriers. Fig. (b) shows the energy level of donor impurity atom.

***p-type semi-conductor*:** A p-type semiconductor is obtained by adding a *trivalent* impurity like indium to an intrinsic semi-conductor. Fig. (a) below shows the impurity atom as dark circle. Since impurity atom has only three valency electrons in its outermost orbit, it shares these three electrons with neighbouring semiconductor atoms. However, one covalent bond shown by dotted line in fig. (a) remains incomplete.





The impurity atom can complete its covalent bond by *accepting* an electron from a neighbouring semi-conductor atom. However, the deficiency of hole is still present but has moved. Since a hole is equivalent to a positive charge, the movement of a hole constitutes current. The current flowing depends on the number of holes present. Since one impurity atom produces one hole, the number of holes present depends on the *extent of doping.* If the doping is to the extent of one impurity atom per million atoms of semiconductor, the number of

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holes present per c.c. is about 10^{17}. These positively charged holes are the majority charge carriers. Fig. (b) shows the energy level of acceptor atoms.

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Q.48. *A n-type and p-type semiconductors are formed by doping silicon to same extent. Under identical conditions which one will have more free current? Give reasons in support of your answer.* **(2)**

Ans. The n-type semiconductor will have more current than p-type semi conductor. The *mobility* of electrons is more than the mobility of holes.

Q.49. *Number of free electrons and holes per unit volume in a semi-conductor is 10^{10} and 10^{4} respectively. Is it a n-type or p-type semiconductor ?* **(1)**

Ans. Since, number of free electrons per unit volume is more than the number of holes per unit volume; the material is a n-type semiconductor.

Q.50. *Why an extrinsic semiconductor gets damaged permanently, if its temperature rises above a critical temperature?* **(2)**

Ans. When the temperature of extrinsic semicondutor is raised above the critical temperature, the number of broken bonds is very large. The majority to minority charge carrier ratio is significantly alterred. The movement of the majority and minority charge carriers does not remain as planned while making the semiconductor. Therefore, the semiconductor behaves differently or is damaged.

Q.51. *An n-type semiconductor has a large number of free electrons but still it is electrically neutral. Comment.* **(2)**

Ans. In a n-type semiconductor the impurity atoms have five electrons in outermost orbit. Four of these five electrons form covalent bonds with neighbouring atom of silicon (or germanium). The fifth electron is the free electron. However, the atom as a whole is electrically neutral, therefore, n-type semiconductor is also neutral.

Q.52. *What do you know about the location of the acceptor level in a p-type semiconductor?* **(1)**

Ans. In a p-type semiconductor the energy level of the acceptor impurity atom is empty and is near the full valency band.

Q.53. *What is the effect of temperature on the formation of electron-hole pairs in semiconductors.* **(2)**

Ans. In a pure (or intrinsic) semiconductor the ratio of free electrons and holes remains unity at all temperatures. As temperature rises the number of free electrons and holes increases.

In an extrinsic semiconductor; the number of minority charge carriers increases as temperature rises. The ratio of the number of majority to minority charge carriers per unit volume decreases as temperature increases.

Q.54. *Give the ratio of the number of holes and the number of conduction electrons in an intrinsic semi-conductor.* **(CBSE 1997) (1)**

Ans. The required ratio is unity.

Q.55. *Draw energy band diagram for a*

(i) n-type extrinsic semiconductor. **(CBSE 1998) (1)**

(ii) intrinsic semiconductors. **(CBSE 1998) (1)**

Ans. See answers to question no. 44 and 36.

Q.56. *Distinguish between n-type and p-type semiconductors on the basis of energy band diagram.* **(CBSE 1997) (2)**

Ans. See answer to question no. 47.

Q.57. *Distinguish between conductors, insulators and semiconductors on the basis of energy band diagrams.* **(CBSE 1998) (3)**

Ans. See answer to question no. 23.

Q.58. *Draw energy band diagram of: (i) n-type and (ii) p-type semiconductors.* **(CBSE 1998) (3)**

Ans. See answer to questions no. 47.

Q.59. *How does the energy gap in an intrinsic semiconductor vary when doped with a pentavalent impurity?* **(CBSE 2000) (1)**

Ans. It becomes smaller.

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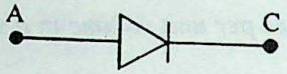
Q.60. *What is a junction diode?*

Ans. A single crystal of silicon or germanium which has been doped in such a manner that half of it, is p-type semiconductor and the other half is n-type semiconductor is called a junction diode. (1)

Q.61. *Give the symbol used to represent a junction diode.*

Ans. (1)



Q.62. *What is a depletion layer?*

Ans. In a junction diode; the electrons from the n-region and holes from the p-region diffuse across the junction. In the immediate vicinity of the junction, there is a depletion of free electrons in n-side and a depletion of holes in p-side. This small region around the junction is known as the depletion region. (1)

Q.63. *What is the size of depletion layer in a p-n junction?*

Ans. About 1 μm (or 10^{-6} m) (1)

Q.64. *What is barrier potential?*

Ans. The difference of potential, in the depletion layer across the junction is known as the barrier potential. (1)

Q.65. *What is the order of magnitude of barrier potential?*

Ans. About 0.7 V in a silicon semiconductor. (1)

About 0.2 – 0.3 V in a germanium semiconductor.

Q.66. *In a p-n junction, why electrons do not keep on flowing from the n-region to the p-region?* (2)

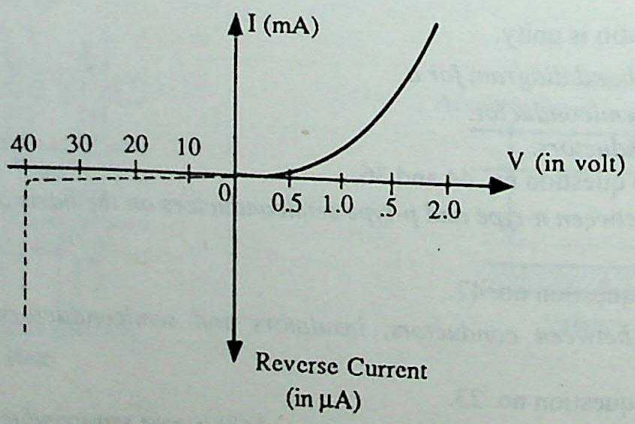
Ans. In a junction diode initially the electrons from n-region diffuse to p region and vice-versa. This diffusion results in production of a barrier potential. The barrier potential produced is such that it exerts a force of replusion on electrons in n-side trying to diffuse to p-side. The same happens to holes in p-region trying to diffuse into n-side. In a state of dynamic equilibrium, there is no net flow of electrons or holes across the junction.

Q.67. *Does a junction diode obey Ohm's law?*

Ans. No; a junction diode does not obey Ohm's law. (1)

Q.68. *Draw the complete characteristic curve of a junction diode?*

Ans. (1)



Q.69. *What is knee voltage in a junction diode?* (1)

Ans. About 0.3 V for germanium. About 0.67 for silicon.

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Q.70. *Draw I versus V graph of a forward biased junction diode.* **(1)**

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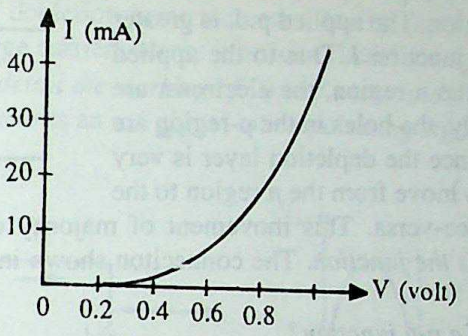
Ans.



Q.71. *Why does a potential difference gets established across the junction of a p-n diode?* **(2)**

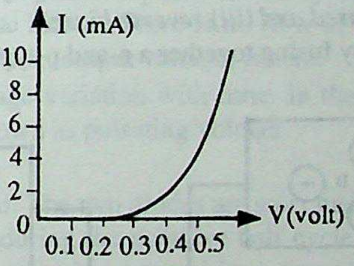
Ans. The potential difference across junction in a p-n diode is established due to diffusion of electrons from n-region to p-region and vice-versa. This is known as barrier potential.

Q.72. *In a p-n junction, due to diffusion, there is an excess of electrons in the p-region in the immediate vicinity of the junction and vice-versa. Why do the excess electrons in the p-region not re-combine and neutralise the excess holes present in the p-region?*

Ans. The electron that diffuse into p-region or the holes that diffuse into n-region are not mobile. The electrons and holes attach themselves losely to the atoms of silicon (or germanium) in the vicinity of junction. Since these electrons or holes are not mobile, they do not undergo recombinations.

Q.73. *What is meant by the characteristic curve of a junction diode? Draw the characteristic curves of a junction diode.* **(2)**

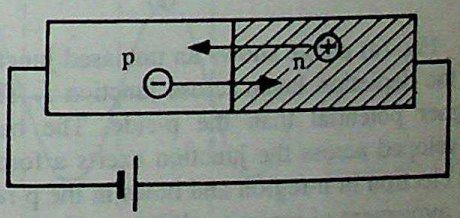
Ans. The graph of anode current (I) and the applied potential (V) is known as the characteristic curve. Fig. below gives the characteristic curve of junction diode, when it is forward biased.



Q.74. *Explain the existence of a very small reverse current in a reverse biased junction diode.* **(2)**

Ans.

Fig. shows a reverse biased p-n junction. The electrons are minority charge carriers in p-region and the holes in the n-region. The applied p.d. makes holes from n-region and electrons from p-region move across junction as shown. This movement of minority charge carriers across junction establishes a current this is known as the reverse current.



Q.75. *What is the resistance of a p-n junction, when it is forward biased?* **(1)**

Ans. Quite small. Of the order of a few ohm.

Q.76. *What is the resistance of a p-n junction, when it is reverse biased?* **(1)**

Ans. Quite high. Of the order of a few kilo-ohm.

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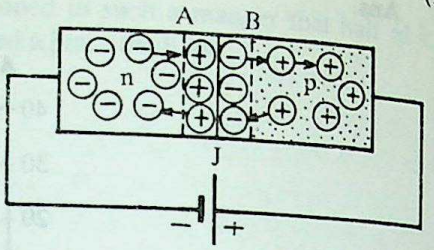
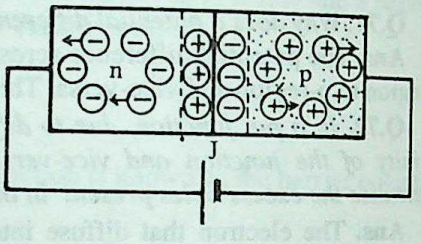
Q.77. *What is forward biasing of a p-n junction?*

Ans. Fig. alongside shows a junction diode connected to an external p.d. The negative of external p.d. is connected to the n-region and the positive to the p-region. The applied p.d. is greater than the barrier potential across the junction J. Due to the applied p.d. the majority charge carriers in the n-region, the electrons, are pushed towards the junction. Similarly, the holes in the p-region are also pushed towards the junction. Since the depletion layer is very thin, most of the electrons are able to move from the n region to the p-region across the junction and vice-versa. This movement of majority charge carriers across the junction results in the *flow of a current across the junction.* The conneciton shown in fig. is known as the, *forward bias, connection of the p-n junction.* (1)



Q.78. *What is reverse biasing of a p-n junction?* (1)

Ans. Fig. alongside shows a junction diode connected to an external p.d. in such a way that the n-region is connected to the positive of the external p.d. and the p-region is connected to the negative. Due to the applied p.d. the electron from n-region and the holes from the p-region are pulled away from the junction. There is no movement of charge carriers across the junction and the current is almost zero. The connection shown in fig., is known as the *'reverse bias'* connection of the p-n junction.



Q.79. *A reverse current of the order of a few* μA *exists in a reverse biased junction diode. Is this statement true?* (1)

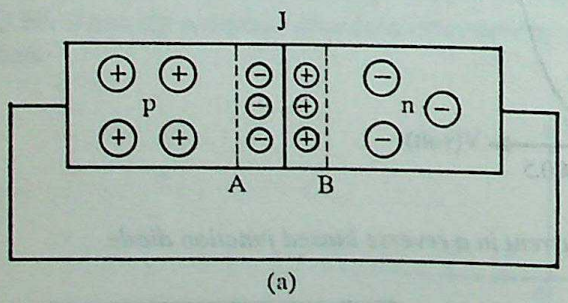
Ans. Yes.

Q.80. *What do you understand by the statement. "a junction diode has a unidirectional current flow"?* (1)

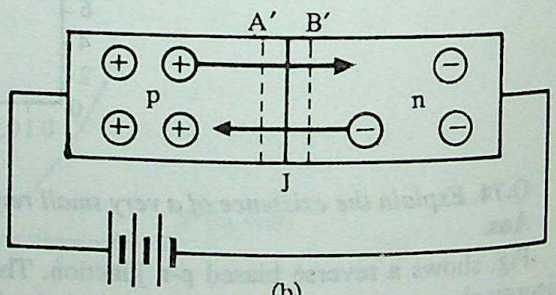
Ans. A current flows across junction diode when it is forward biased. There is no current across junction diode if it is reverse biased. This is known as the unidirectional current flow characteristic of a diode.

Q.81. *What is a junction diode? Explain in detail the working of a junction diode when it is (i) having no external applied voltage (ii) forward biased and (iii) reverse biased.* (3)

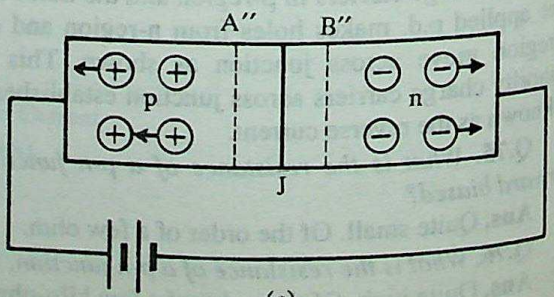
Ans. A junction diode is obtained by fusing together a n-and p-type semiconductor.



(a)



(b)



(c)

Fig. (a) above shows an unbiased junction diode. AB is the depletion layer across junction J. The n side is at higher potential than the p-side. The barrier potential developed across the junction exerts a force of replusion on electron in n-region and holes in the p-region. There is no movement of majority charge carriers across junctions. Therefore, current is zero.

Fig. (b) shows a *forward biased* junction diode. The applied p.d. pushes holes from p-region and electrons from n-region torwards the junction. Due to this the depletion

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layer is reduced. In fig. (b) A′B′ is reduced depletion layer. There is a movement of majority charge carriers across the junction. This results in a flow of current across the junction.

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Fig (c) shows a *reverse biased* junction diode. The applied p.d. pulls electrons from n-region and holes from p-region away from the junction. The depletion layer increases. In fig. (c) A″B″ is increased depletion layer. There is no movement of majority charge carriers across junction. Therefore, there is no current.

Q.82. *What is a rectifier? Give in detail the working of (i) half wave and (ii) full wave rectifier.* **(5)**

Ans. A rectifier is a device that converts an a.c. signal into a pulsating signal.

(i) ***Half-wave rectifier:***

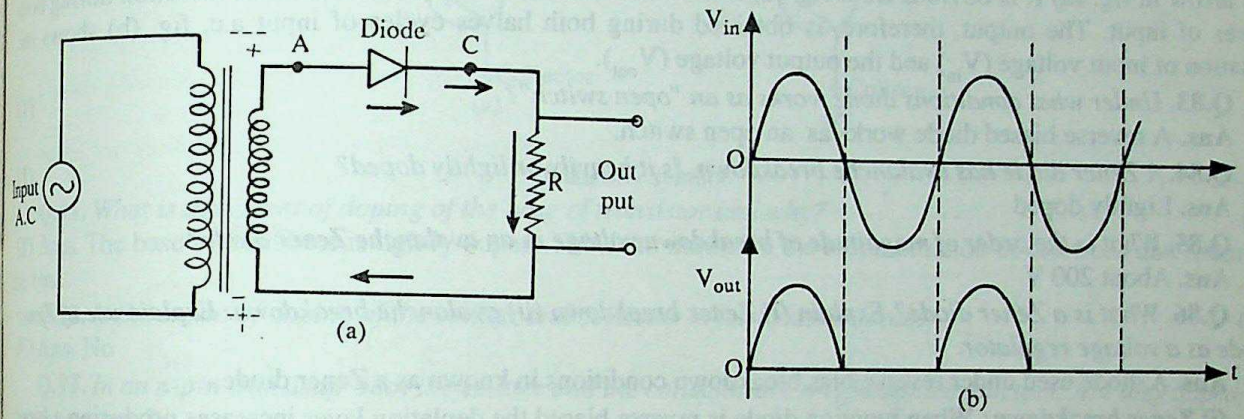

Fig. (a) gives the circuit of a half-wave rectifier. R is the *load resistance*. The p.d. across load resistance R is the *output*. During the positive half-cycle of input signal the polarity is shown by solid line in fig. The anode A is at a higher potential than cathode C. The diode is forward biased. The current in circuit is shown by solid arrow in fig. (a). Due to this current, there is a p.d. across load resistance R. The current and p.d. across load increase or decrease as input voltage increases or decreases.

In fig. (a) the polarity during negative half cycle of input in shown by dotted line. The anode A is at a lower potential than cathode C. The diode is reverse biased. There is no flow of current in circuit. Since, there is no current through load resistance, P.d. across R, (i.e., output voltage) is zero.

Fig. (b) shows the input and output voltage variation with time. In the output, the negative half cycles of input have been chopped off. The output is known as pulsating voltage.

(ii) ***Full-wave rectifier:***

In a full wave rectifier two diodes are used. The two diodes are so connected that one diode conducts during the positive half cycle of input and the other during the negative half cycle of the input voltage. However, the current in load resistance during the both halves of input signal is in same direction. The output across load is, therefore, undirectional.

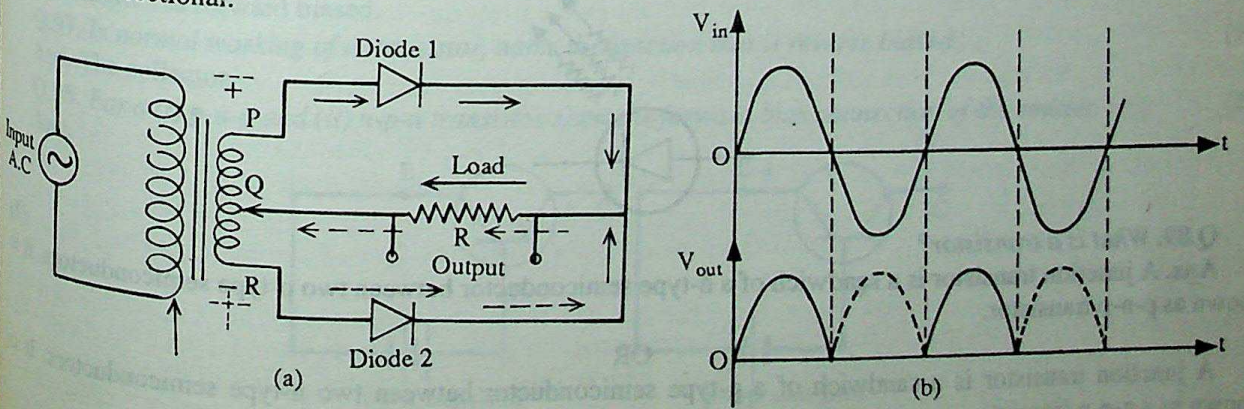

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Fig. (a) shows the circuit of a full-wave rectifier. PQR is the secondary of the *centre-tap transformer*

In fig (a) above the solid lines show polarity during the positive half cycle of input A.C. Point P is at higher potential. Potential decreases on moving from P to R. Point Q is at a lower potential than point P. Diode 1 is forward biased. It conducts direction of current as shown by solid arrow in fig. (a). However, point R is at a lower potential than point Q. Therefore, diode 2 is reverse biased. It does not conduct.

In fig. (a) above the dotted lines show the polarity during the negative half cycle of input A.C. Now point P is at a lower potential than Q. Diode 1 is reverse biased. It does not conduct. However, point R is at a higher potential than Q. Therefore, diode 2 is forward biased. It conducts. The direction of current is shown by dotted line arrow in fig. (a) It is obvious from fig. (a) that current in load resistance R is in same direction during both halves of input. The output, therefore, is obtained during both halves cycles of input a.c. fig. (b) shows the variation of input voltage (V_{in}) and the output voltage (V_{out}).

Q.83. *Under what conditions diode works as an "open switch"?* (1)

Ans. A reverse biased diode works as an open switch.

Q.84. *A Zener diode has avalanche breakdown. Is it heavily or lightly doped?* (1)

Ans. Lightly doped

Q.85. *What is the order of magnitude of breakdown voltage in an avalanche Zener diode?* (1)

Ans. About 200 V

Q.86. *What is a Zener diode? Explain (i) Zener breakdown (ii) avalanche breakdown. Explain use of Zener diode as a voltage regulator.* (3)

Ans. A diode used under reverse bias breakdown conditions in known as a Zener diode.

(i) Zener breakdown: When junction diode is reverse biased the depletion layer increases producing a large barrier potential. If the field due to the barrier potential is strong enough to tear away electrons from the atoms of the semiconductor producing more electron-hole pairs. The number of minority charge carriers increases appreciably. The movement of large minority charge carriers across the junction produces large reverse current. This process is known as Zener breakdown.

(ii) Avalanche breakdown: Avalanche breakdown occurs in diodes having low doping and the breakdown voltage is of the order of a few hundred volt. Under such high reverse bias voltage the minority carriers gain sufficient kinetic energy to produce secondary ionisation by collision. The secondary ions produced can further cause ionisation by collision. This results in an avalanche of ions and a large reverse current.

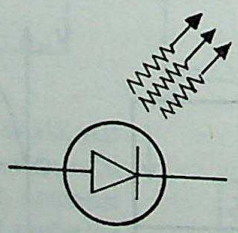
(iii) Voltage regulator: A Zener diode operating a little above the breakdown voltage under reverse bias condition acts as a voltage regulator. Under these conditions the reverse current is independent of the applied voltage. The voltage drop across the Zener diode remains same even when the applied voltage fluctuates. This is voltage regulation.

Q.87. *What does the term LED stand for?* (1)

Ans. Light - emitting - diode

Q.88. *Give the symbol of a LED.* (1)

Ans.



Q.89. *What is a transistor?* (1)

Ans. A junction transistor is a sandwich of a n-type semiconductor between two p-type semiconductors. It is known as p-n-p transistor.

OR

A junction transistor is a sandwich of a p-type semiconductor between two n-type semiconductors. It is known as a n-p-n transistor.

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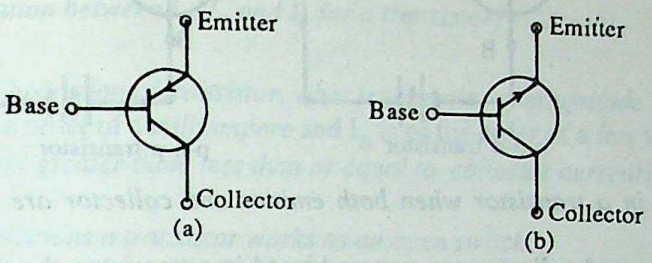
Q.90. *Draw the symbol of a (i) n-p-n and (ii) p-n-p transistor.* **(1)**

Ans. Fig. (a), (b) shows the symbol used to represent a p-n-p and a n-p-n transistor respectively.



Transistor symbol

Q.91. *What is the extent of doping of the base of transistor and why?* **(2)**

Ans. The base of transistor is lightly doped. This is to minimise the recombination of electrons and holes in the base.

Q.92. *Is the extent of doping of the emitter and collector in a transistor same?* **(1)**

Ans. No

Q.93. *In an n-p-n transistor both the emitter and the collector are n-type semiconductors. Are they doped to the same extent?* **(1)**

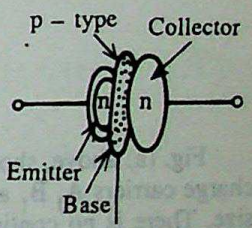
Ans. No. Emitter is heavily doped and the collector is lightly doped.

Q.94. *Under normal operation of transistor, which junction is forward biased and which junction is reverse biased?* **(1)**

Ans. Emitter junction is forward biased and the collector junction is reverse biased.

Q.95. *In a practical transistor, can we interchange the emitter and collector? Give reasons in support of your answer.* **(2)**

Ans. No. Though both emitter and collector are semiconductors of same type they differ from one another in two important respects. (i) The amount of doping of emitter is much more than that of the collector. (ii) The contact area of the collector with base is much more than that of the emitter with the base. This is shown in fig.



Q.96. *In normal working of a transistor, is emitter forward or reverse biased?* **(1)**

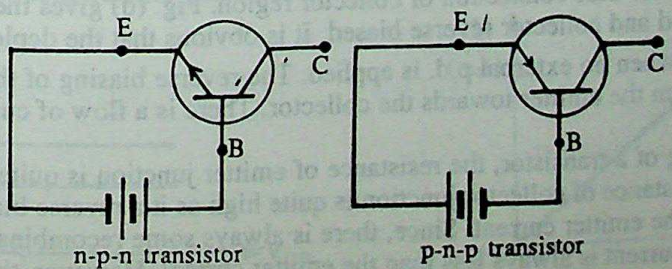
Ans. Emitter is forward biased.

Q.97. *In normal working of a transistor, name the junction that is reverse biased.* **(1)**

Ans. The collector.

Q.98. *For a (i) p-n-p and (ii) n-p-n transistor show the forward bias connection of the emitter.* **(2)**

Ans.



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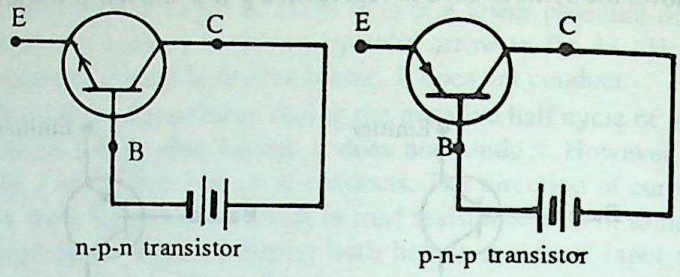
Q.99. *For a (i) p-n-p and (ii) n-p-n transistor show the reverse bias connection of the collector.* (2)

Ans.



n-p-n transistor p-n-p transistor

Q.100. *What happens in a transistor when both emitter and collector are reverse biased. What is this condition known as?* (2)

Ans. When both emitter and collector are reverse biased in a transistor, the transistor does not work. This condition is known as the cut-off. In this position transistor works as open-switch.

Q.101. *What is a transistor ? Explain in detail the working of a n-p-n or p-n-p transistor.* (3)

Ans.

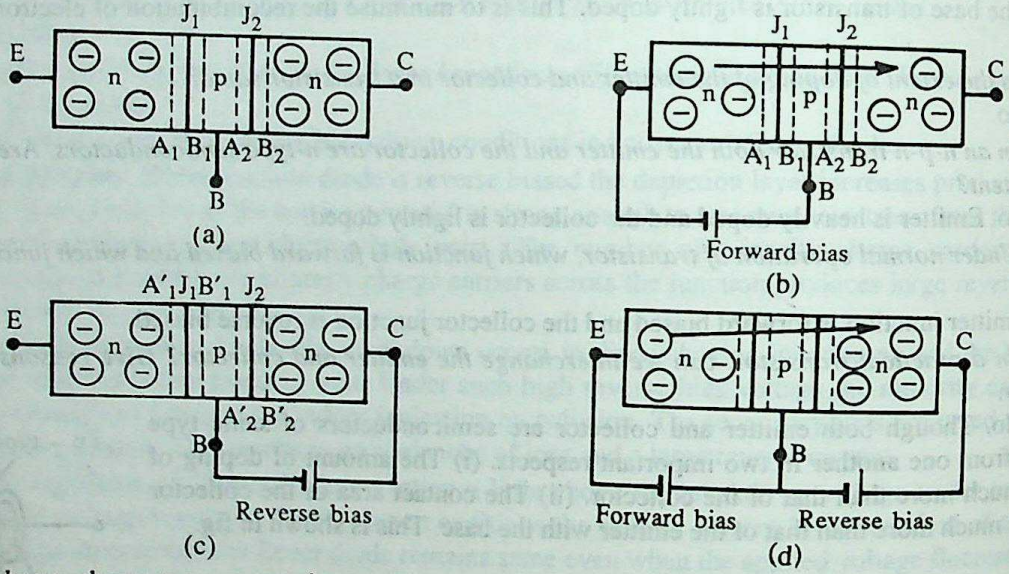


Fig. (a) above, shows a n-p-n transistor with no external p.d. applied across it. Due to diffusion of majority charge carriers A_1 B_1 and A_2 B_2 is the depletion layer at the two junctions. The two depletion layers have same size. There is no continuous movement of charge carriers across junctions J_1 and J_2 and therefore there is no current.

Fig. (b) shows an externally applied p.d. so that the emitter junction J, is forward biased. The majority charge carriers in the n-region (i.e., the electrons) are pushed towards junction J_1. The new depletion layer A_1' B_1' across junction J_1 is smaller than before. The base region being very thin and lightly doped the electrons are able to pass through the base without appreciable recombinations. The barrier potential at junction J_2 helps the movement of electrons to the n-region (i.e., the collector). There is a flow of current in transistor.

Fig. (c) shows the reverse bias connection of collector region. Fig. (d) gives the connection of external p.d. with emitter forward biased and collector reverse biased. It is obvious that the depletion A_2' B_2' across junction J_2 is more than, what it is when no external p.d. is applied. The reverse biasing of the collector further helps the movement of electrons from the emitter towards the collector. There is a flow of current across both the emitter and the collector junction.

In the normal working of a transistor, the resistance of emitter junction is quite low as it is forward biased. On the other hand, the resistance of collector junction is quite high as it a reverse biased. However, the collector current is nearly same as the emitter current. Since, there is always some recombination of electron-holes in the base region, the collector current is always less than the emitter current. However, the current is transferred from a low resistance input to a high resistance output. This fact is used to produce amplification using a transistor and the transistor derives its name from this action.

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Q.102. *Name the transistor parameters.* **(1)**

Ans. The transistor parameters are :

(i) Emitter current (I_E) (ii) Collector collector (I_C) (iii) Base current (I_B) (iv) Emitter base voltage (V_{EB}) (v) Collector-base voltage (V_{CB}).

Q.103. *What is the relation between I_B, I_E and I_C for a transistor?* **(1)**

Ans. $I_E = I_C + I_B$.

Q.104. *For the normal operation of transistor, what is the order of magnitude of I_E, I_C and I_B?* **(1)**

Ans. I_E and I_C are of the order of a *milliampere* and I_B is of the order of a few tens of microampere.

Q.105. *Is emitter current greater than, less than or equal to collector current?* **(1)**

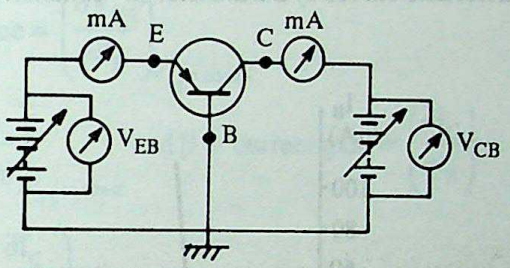
Ans. $I_E > I_C$

Q.106. *Under what conditions a transistor works as an open switch?* **(1)**

Ans. A transistor works as an open switch in its "cut-off" region, i.e., the emitter is reverse biased.

Q.107. *Draw the circuit of a n-p-n transistor in "common base" configuration.*

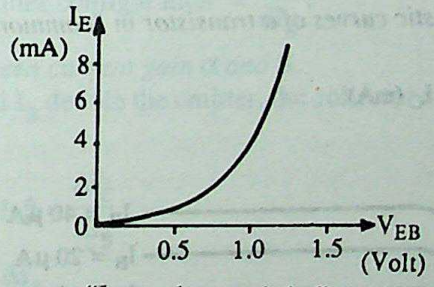
Ans.



Common-base configuration of a p-n-p transistor

Q.108. *Draw the input characteristic curve of a transistor in "common base" configuration.* **(1)**

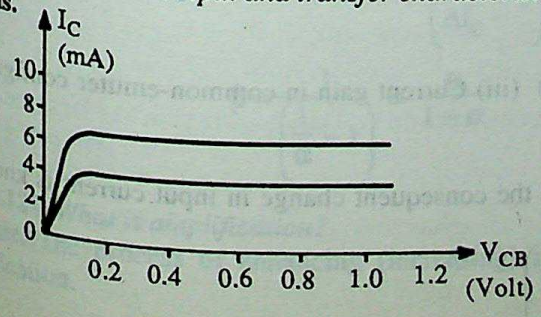
Ans.



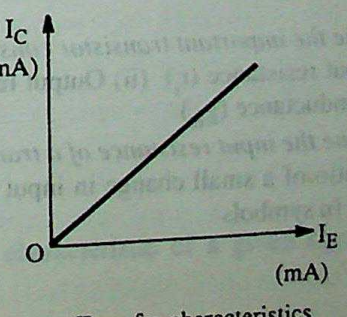
"Input characteristics"

Q.109. *Draw the output and transfer characteristic of a transistor in "common base" configuration.* **(1)**

Ans.



"Output characteristics"



Transfer characteristics

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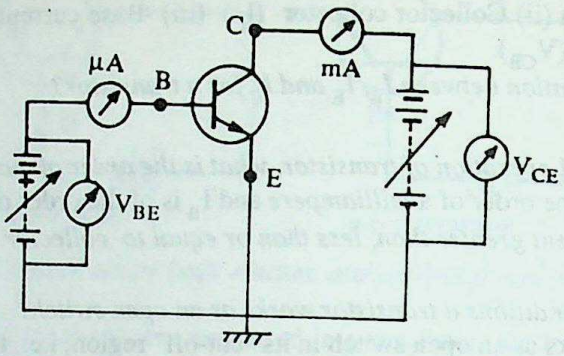
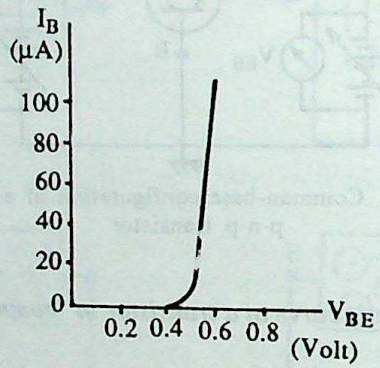
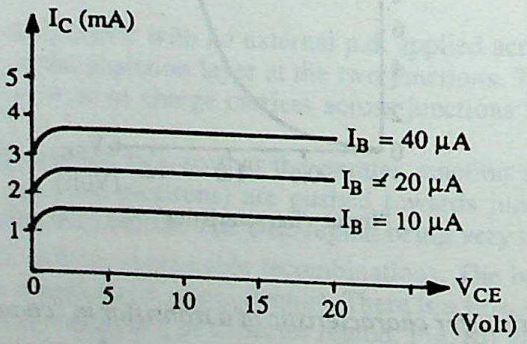
Q.110. *Draw the circuit of an n-p-n transistor in "common emitter" configuration.*
Ans. (1)



Q.111. *Give the input characteristic curves of a transistor in "common emitter" configuration.* (1)
Ans.



Q.112. *Give the output characteristic curves of a transistor in "common emitter" configuration.* (1)
Ans.



Q.113. *Name the important transistor constants.* (1)
Ans. (i) Input resistance (r_i) (ii) Output resistance (r_o) (iii) Current gain in common-emitter configuration (β) (iv) Transconductance (g_m).

Q.114. *Define the input resistance of a transistor.* (1)
Ans. The ratio of a small change in input voltage and the consequent change in input current is known as input resistance. In symbols

$$r_i = \left(\frac{\partial V_i}{\partial I_i}\right)$$

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Q.115. *Define the output resistance of a transistor.* **(1)**

Ans. The ratio of a small change in output voltage and the corresponding change in output current is known as output resistance. In symbols $r_0 = \left(\frac{\partial V_0}{\partial I_0}\right)$.

Q.116. *Define the transconductance of a transistor.* **(1)**

Ans. The transconductance (g_m) is the ratio of change in output current and the corresponding change in input voltage. In symbols, $g_m = \frac{\partial I_0}{\partial V_i}$.

Q.117. *In a common base circuit of a transistor, is the input and output resistances high or low?* **(1)**

Ans. In common-base configuration the input resistance is low and the output resistance is high.

Q.118. *For a transistor show that $g_m = \beta/r_i$, where the symbols have their usual meanings.* **(2)**

Ans. Consider a transistor in a common emitter configuration.

By definition, r_i = input resistance = $\left(\frac{\partial V_{BE}}{\partial I_B}\right)_{V_{CE} = \text{const.}}$

g_m = trans-conductance = $\left(\frac{\partial I_C}{\partial V_{BE}}\right)_{V_{CE} = \text{const}}$ and β = current gain = $\left(\frac{\partial I_C}{\partial I_B}\right)$

Obviously, $\frac{\beta}{r_i} = \frac{\partial I_C}{\partial I_B} \times \frac{\partial I_B}{\partial V_{BE}} = \left(\frac{\partial I_C}{\partial V_{BE}}\right) = g_m$.

Q.119. *Define for a transistor, the current gain α and β.* **(2)**

Ans. α = current gain in common-base configuration = $\frac{\partial I_C}{\partial I_E}$.

β = current gain in common emitter configuration = $\frac{\partial I_C}{\partial I_B}$.

Q.120. *Obtain the relation between current gain α and β.* **(2)**

Ans. In a transistor, let I_E, I_C and I_B denote the emitter, the collector and the base current respectively.

we know $I_E = I_C + I_B$ ...(i)

Also by definition, $\alpha = \frac{\Delta I_C}{\Delta I_E}$ and $\beta = \frac{\Delta I_C}{\Delta I_B}$

From equation (i), $\Delta I_E = \Delta I_C + \Delta I_B$

$\therefore$ $$\beta = \frac{\Delta I_C}{\Delta I_E - \Delta I_C} = \frac{1}{\left(\frac{\Delta I_E}{\Delta I_C} - 1\right)}$$

or $$\beta = \frac{1}{\left(\frac{1}{\alpha} - 1\right)} = \frac{\alpha}{1 - \alpha}$$

Q.121. *What is amplification?* **(1)**

Ans. The process of enhancing (increasing) any desired characteristic of a given signal, is known as amplification.

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Q.122. *Define the "voltage gain" of an amplifier.* (1)

Ans. The voltage gain of an amplifier is the ratio of the change in the output voltage and the corresponding change in input voltage. Expressed mathematically, voltage gain = $\frac{\Delta V_0}{\Delta V_i}$.

Q.123. *Write an expression for gain of a "common emitter" transistor amplifier.* (1)

Ans. For a common-emitter amplifier; voltage gain = $A_V = -R_L\left(\frac{\beta}{r_i}\right)$,

where R_L = load resistance; r_i = input resistance and β = current gain in common emitter configuration.

Q.124. *What is source of energy in an amplifier?* (1)

Ans. The d.c. batteries used in circuit are the source of energy.

Q.125. *What is the phase relation between the input and output signals in amplifier?* (1)

Ans. There is a phase difference of 180° between the input and the output signals.

Q.126. *What is the relation between voltage gain, transconductance and load resistance of common emitter transistor amplifier?* (1)

Ans. Voltage gain = $-g_m R_L$

Q.127. *From the relation $A_v = -g_m R_L$, it appears that gain A_v can be increased indefinitely by increasing R_L. Is it so? Explain.* (2)

Ans. No. The following is the main reason.

As R_L increase, the voltage between collector and emitter (V_{CE}) decreases. A stage is reached when both emitter and collector are forward biased. The transistor goes into its saturation region and the amplifier does not work.

Q.128. *Is the voltage gain A_v of a common emitter amplifier, a constant irrespective of the magnitude of the input signal? Explain.* (2)

Ans. No. During the positive half cycle of the input signal, the base current (I_B) increases. This produces an increase in collector current (I_C). As I_C increases, V_{CE} decreases [$V_{CE} = V_{CC} - I_C R_L$]. If I_C is large enough, the transistor is driven into saturation region. Therefore, if $\beta I_B \geq I_C$ the transistor circuit does not work as an amplifier.

Q.129. *What is an oscillator?* (1)

Ans. An oscillator is a device that produces a signal of constant amplitude and frequency.

Q.130. *What is the basic oscillator circuit?* (1)

Ans. A L-C circuit also known as "tank-circuit" is the basic oscillator circuit.

Q.131. *Does the basic oscillator circuit produce oscillations of constant amplitude?* (1)

Ans. No. It produces oscillations in which amplitude of oscillations decreases with time.

Q.132. *What is feed back?* (1)

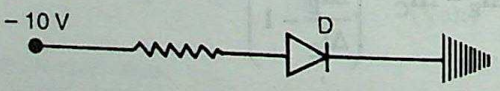
Ans. The process of giving back a fraction of the output to the input, is known as feedback.

Q.133. *What is phase difference between input and output of the feedback network in an oscillator?* (1)

Ans. 180°.

Q.134. *In the given diagram, is the diode D forward or reversed biased?* **(CBSE 1997)** (1)

Ans. Reverse biased.



Q.135. How does the collector current change in a junction transistor, if the base region has larger width? **(CBSE 1999)** (1)

Ans. The collector current decreases.

Q.136. *How does the thickness of the depletion layer in a p-n junction vary with increase in reverse bias?* **(CBSE 1999)** (1)

Ans. The thickness of the depletion layer increases.

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Q.137. *Write the function of base region of a transistor. Why is this region made thin and slightly doped?*

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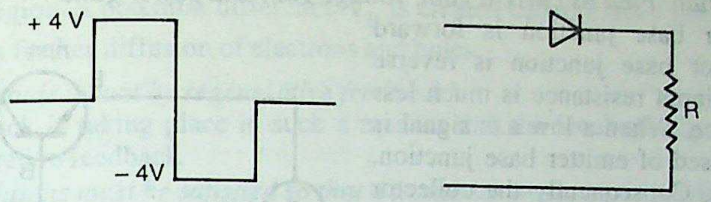
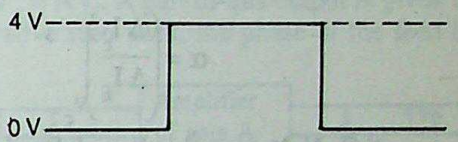
(CBSE 1998) (2)



Ans. In a transistor the base region forms junctions with the emitter region and collector region. The base region of a transistor made thin and doped to minimise the recombination of electrons and holes in the base.

Q.138. *What is an ideal diode? Draw the output waveform across R, for the input waveform given below.*

(CBSE 1999) (2)

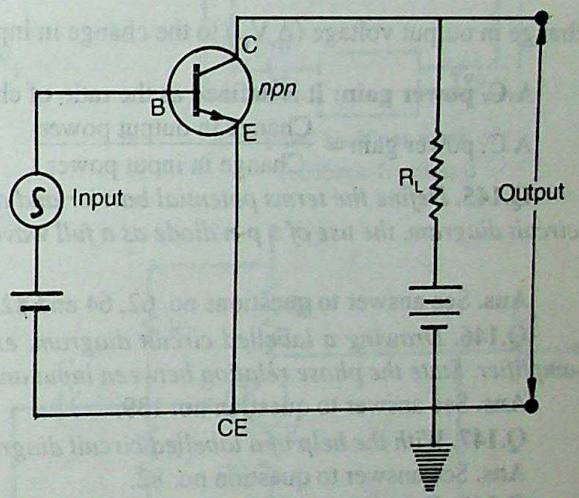


Ans. Ideal diode is a device which starts conducting exactly when forward biased and do not conduct at all when reverse biased.

The output waveform across R is shown in fig below.

Q.139. *Draw a circuit diagram of a common emitter amplifier using a n-p-n transistor. Prove that in this amplifier, the output voltage is 180° out of phase with the input voltage.*

(CBSE 1997, Comptt.) (3)



Ans. When the positive half cycle of input a.c. signal voltage comes, it supports the forward biasing of the emitter base current, due to which emitter current increases and consequently collector current increases. As a result the collector voltage V_{CE} decreases, since,

$V_{CE} = V_{CC} - I_C R_L$

Hence, as the input signal goes through its positive half-cycle, the output goes through its negative half cycle. Similarly, as the input goes through its negative half-cycle, the output goes through its positive half-cycle.

Hence, in a common emitter amplifier output voltage is 180° out of phase with the input voltage.

Q.140. *Draw a circuit diagram to show the biasing of an n-p-n transistor. Explain the transistor action.*

(CBSE 1997) (3)

Ans. See answers to question no. 110.

Q.141. *Define the terms potential barrier and depletion region of a p-n junction diode. State how the thickness of depletion region will change when the p-n junction diode is (i) forward biased (ii) reversed biased.*

(CBSE 1998) (3)

Ans. See answers to question no. 62, 64 for 1st part

(i) When a p-n junction diode is forward biased, thickness of depletion layer decreases.

(ii) When a p-n junction diode is reverse biased, thickness of depletion layer increases.

Q.142. *With the help of a labelled diagram, explain the use of a transistor as an oscillator.*

(CBSE 1998, 2000) (3)

Ans. See Text.

Q.143. *With the help of a labelled circuit diagram, explain the use of an n-p-n transistor as an amplifier.*

(CBSE 1999) (5)

Ans. See Text..

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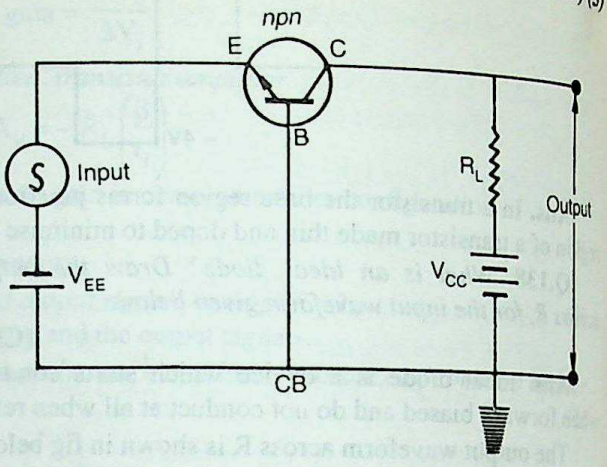
Q.144. *Drawing a labelled diagram, explain how a p-n-p transistor can be used as an amplifier in common base configuration. Find its current gain, voltage gain and power gain.* **(CBSE 1997) (5)**

Ans. Here, emitter base junction is forward biased and the collector base junction is reverse biased. As a result the input resistance is much less than the output resistance. When a low a.c. signal is sent on the forward biased of emitter base junction, emitter current changes. Consequently the collector current changes and, hence, the output voltage according to the relation $V_0 = V_{CC} - I_C R_L$.



A.C. current gain: It is defined as the ratio of change in collector current (ΔI_C) to the change in emitter current (ΔI_E) at constant collector voltage.

$$\alpha = \left(\frac{\Delta I_c}{\Delta I_E}\right)_{V_c}$$

A.C. Voltage gain: It is defined as the ratio of change in output voltage (ΔV_O) to the change in input voltage (ΔV_i). $V_v = \dfrac{\Delta V_O}{\Delta V_i}$

A.C. power gain: It is defined as the ratio of change in output power to the change in input - power.

$$\text{A.C. power gain} = \frac{\text{Change in output power}}{\text{Change in input power}}$$

Q.145. *Define the terms potential barrier and depletion region for a p-n junction. Explain with the help of a circuit diagram, the use of a p-n diode as a full wave rectifier. Draw the input and output waveforms.* **(CBSE 1998) (5)**

Ans. See answer to questions no. 62, 64 and 82.

Q.146. *Drawing a labelled circuit diagram, explain the working principle of a common emitter transistor amplifier. State the phase relation between input and output signals.* **(CBSE 2000) (5)**

Ans. See answer to question no. 139.

Q.147. *With the help of a labelled circuit diagram, explain the rectification action of a full wave rectifier.*

Ans. See answer to question no. 82. **(CBSE 2000) (3)**

Q.148. *If the base region of a transistor is made large as compared to a usual transistor, how does it affect; (i) the collector current? (ii) current gain of this transistor?*

What is the phase difference between the input and output signals of a common emitter amplifier? **(CBSE 2000) (3)**

Ans. If the base region is made thick, most of the charge carriers coming from the emitter would get neutralized in the base by the electron-hole recombination and, hence, would be:

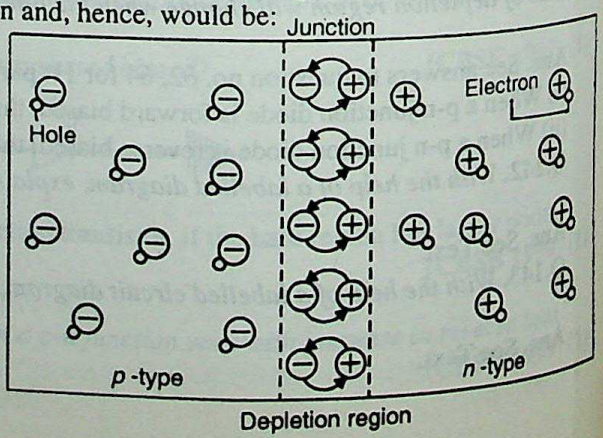
(i) reduced collector current, (ii) reduced current gain.

For common emitter amplifier, the phase difference between input and output signals is 180°.

Q.149. ***Explain how the depletion layer and barrier potential are formed in a p-n junction diode.***

(CBSE 2000) (3)

Ans. In a p-n junction diode, due to higher concentration of electrons on n-side and holes on p-side, diffusion of electrons towards p-side and holes towards n-side takes place. Hence, a recombination of electrons and holes takes place in the immediate vicinity of junction.



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Hence, a region of unneutralized positive ions on n-side and negative ions on p-side is formed near the junction which is depleted of mobile charges. It is called depletion region.

In the depletion region, a potential difference V_B is created called barrier potential as it creates an electric field E_B which opposes further diffusion of electrons and holes.

Q.150. *Explain what is meant by regenerative feedback?* **(2)**

Ans. If the feedback is taking place in such a manner that the feedback signal is *in phase* with the input signal we have regenerative feedback.

Q.151. *What conditions must be satisfied so that a transistor works as an oscillator?* **(1)**

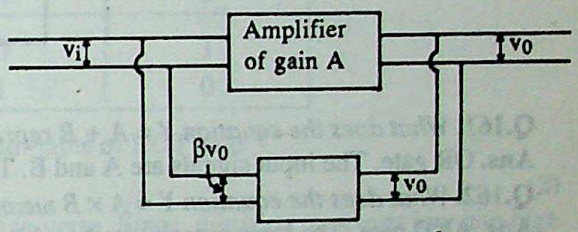
Ans. $A\beta = 1$, where A is the gain of amplifier and β is the feedback fraction.

Q.152. *What are self sustained oscillations?* **(1)**

Ans. If oscillations are produced in such a manner that no continuous external input signal is required; the oscillations are self-sustained.

Q.153. *Obtain the Barkhausen criterion for sustained oscillations.* **(3)**

Ans. Fig. alongside shows an amplifier of gain A. The output $V_o = AV_i$. A part of this output is given back as input via feedback network of feedback fraction β. For regenerative feed back, the phase of the feed back fraction must be same as that of the input V_i. However, in an amplifier there is a phase difference of 180° between the output (V_o) and the input (V_i).



Feed back net work of feedback fraction β

The feedback network produces an additional phase difference of 180°. For self-sustained oscillation

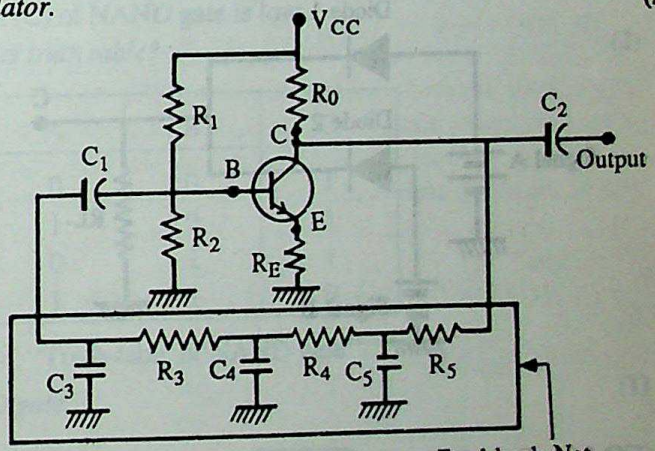
$$V_i = \beta V_o = A\beta V_i$$

$$\therefore \quad A\beta = 1$$

This is known as the Barkhausen criterion.

Q.154. *Draw the circuit diagram of a R-C oscillator.* **(2)**

Ans.



Q.155. *Express decimal number 33 in binary notation.* **(1)**

Ans.

2	33	Remainder
2	16	1
2	8	0
2	4	0
2	2	0
2	1	0
	0	1

Decimal number 33 in binary notation is represented as 100001

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Q.156. *Express binary number 1100101 in decimal notation.*

Ans. $1100101 = 1\times2^6 + 1\times2^5 + 0\times2^4 + 0\times2^3 + 1\times2^2 + 0\times2^1 + 1\times2^0$ (1)

$= 64 + 32 + 4 + 1 = \mathbf{101}.$

Q.157. *What is logic gate?*

Ans. A logic gate is a circuit with one or more than one inputs but one output. The output occurs for a particular combination of inputs. (1)

Q.158. *How are binary numbers represented in a logic circuit?*

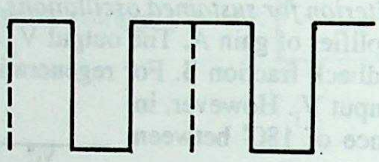
Ans. In a logic circuit binary 1 is expresed a high voltage pulse and binary 0 is represented as a low voltage. (2)

Q.159. *What is positive logic?*

Ans. In positive logic high voltage represents binary number 1 and low voltage represents binary number 0. (1)

Q.160. *Using positive logic and pulses represent binary number 101101.*

Ans. (1)



Q.161. *What does the equation $Y = A + B$ represent in Boolean algebra?*

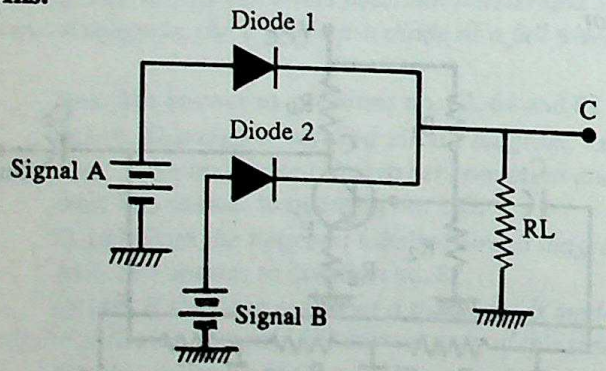
Ans. OR gate. The input signals are A and B. The output signal is Y. (1)

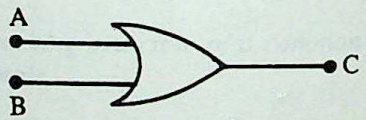
Q.162. *What does the equation $Y = A \times B$ mean in Boolean algebra?*

Ans. AND gate. The input signals are A and B. The output signal is Y. (1)

Q.163. *Draw the circuit diagram of an OR gate using diodes. Give the logic symbol of OR gate.* (2)

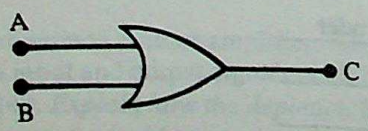
Ans.





Q.164. *Give the symbol and the truth table of the OR gate.* (2)

Ans.



Logic symbol of OR-gate

A	B	C
0	0	0
1	0	1
0	1	1
1	1	1

"Truth-table of OR-gate"

Q.165. *Under what conditions, is the output of an OR gate high?* (1)

Ans. When either or both the input signals are high, the output of OR gate is high.

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Q.166. *What is the number of (i) inputs and (ii) outputs in an AND gate?* **(1)**

Ans. (i) Two input (ii) One output

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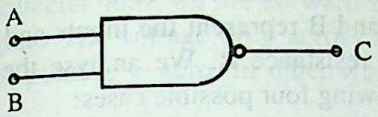
Q.167. *Give the symbol and the truth table of the AND gate.* **(2)**

Ans.



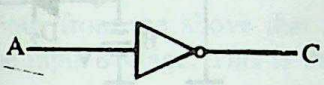
Logic Symbol of AND Gate

A	B	C
0	0	0
1	0	0
0	1	0
1	1	1

"Truth-table of AND gate"

Q.168. *Give the symbol and the truth table of NOT gate.* **(2)**

Ans.



A	B
0	1
1	0

"Truth-table of NOT gate"

Q.169. *Why is a NOT gate known as an invertor?* **(2)**

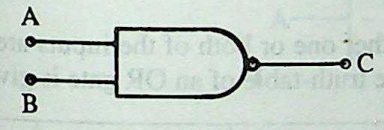
Ans. In a NOT gate the output is low if input is high and vice-versa. Since, it inverts (converts low into high and vice-versa) it is also known as an invertor.

Q.170. *Under what conditions output of a NAND gate is low?* **(1)**

Ans. When both inputs A and B are high the output (C) of NAND gate is low.

Q.171. *What is the symbol of a NAND gate? Give its truth table?* **(2)**

Ans.



Logic Symbol of NAND Gate

A	B	C
0	0	1
1	0	1
0	1	1
1	1	0

"Truth-table of NAND gate"

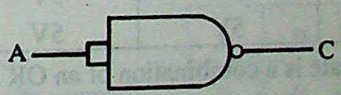
Q.172. *Name the logic gates used to make a NAND gate.* **(1)**

Ans. (i) AND and (ii) NOT gate.

Q.173. *How can a NAND gate be used as inverter?* **(2)**

Ans. If both input terminals of a NAND gate are joined together, it works as a NOT gate.

This is shown in fig. alongside.



Q.174. *Why do we call, the NAND gate as the "universal gate"?* **(2)**

Ans. All gates can be obtained by a suitable combination of NAND gates. Therefore, NAND gate is known as a "universal gate."

Q.175. *What gate is equivalent to a NAND gate having both its inputs A and B connected together?* **(1)**

Ans. NOT - gate.

Q.176. *How many NAND gates are required to produce a NOT gate?* **(1)**

Ans. One.

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Q.177. *How many NAND gates are required to produce a AND gate?*
Ans. Two.
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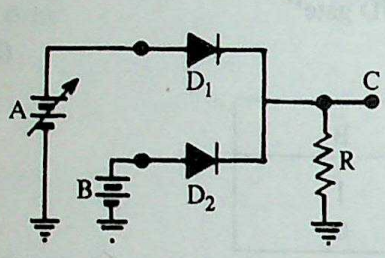
(1)

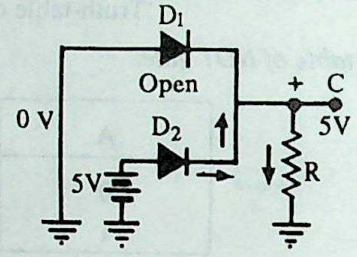
Q.178. *How many NAND gates are required to fabricate OR gate?*
Ans. Three.
(1)

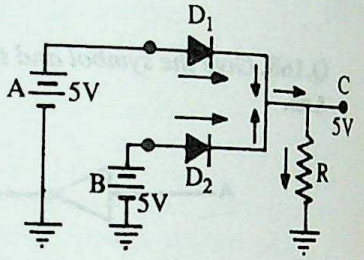
Q.179. *Draw the circuits and explain the working of the OR gate. What is a NOR gate?*
(5)

Ans. Fig. below shows the circuit of a *two input* OR gate. A and B represent the inputs and the output is taken across point C. D_1 and D_2 are two diodes connected to a resistance R. We analyse the OR gate by considering input voltage to be either zero or 5V. There are the following four possible cases:

Case I. The input voltage applied to plate at both A and B is zero. Since, there is no voltage to either diode none of them conducts. The current being zero, there is no voltage drop across C. This means that output C is also zero.







Case II. Let input A = 0 and B = 5 V. Now diode D_2 is forward biased and it conducts. However, diode D_1 does not conduct. The current produced by diode D_2 flows through resistance R producing a voltage drop across it. The output voltage at C is, therefore, high voltage. This is shown in fig. (b).

Case III. Now let A = 5 V and B = 0. Obviously, now diode D_1 conducts producing an output voltage across C. The output across C is high.

Case IV. When A = 5 V and B = 5 V, *i.e.*, both inputs are high both diodes D_1 and D_2 are forward biased. The voltage across D_1 and D_2 are in parallel, therefore, voltage across R is high and is 5 V. This means that when both inputs are high the output is high as shown in fig. (c).

We can summarise and say that there is a high output when either one or both of the inputs are high. These results are also represented in what are known as the truth-table. The truth-table of an OR gate is given below.

Input A	B	Output C
0V	0V	0V
0V	5V	5V
5V	0V	5V
5V	5V	5V

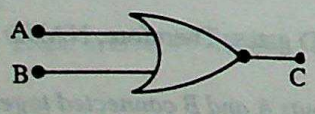
OR

A	B	C
0	0	0
0	1	1
1	0	1
1	1	1

A NOR gate is a combination of an OR and a NOT gate.

Q.180. *Give the logic symbol and truth table of a NOR gate.*
(2)

Ans.



A	B	C
0	0	1
1	0	0
0	1	0
1	1	0

"Truth-table of NOR gate"

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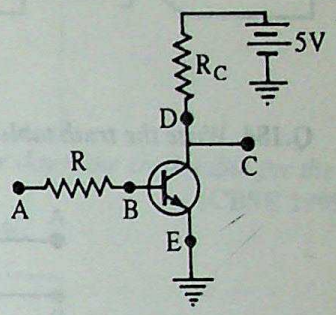
Q.181. *Explain how the circuit of a NOT gate is set up using a transistor. Discuss the working of the circuit.* **(3)**

Ans. Fig. alongside shows the basic circuit of a NOT gate employing n-p-n transistor. Let the input voltage at A be high say 5 V. Now both emitter and collector junction are forward biased. The transistor works in saturation region. The voltage drop across resistance R_C is almost 5 V so that voltage of point C is zero. In other words, when the input is high the output is low.



Let now that input voltage below, *i.e.*, point A is at 0V. Now the base emitter junction is not forward baised and emitter current, is zero. The transistor, now, is "cut-off'. Since, there is no emitter current and consequently no collector current the voltage drop across resistance R_c is zero.

Obviously, therefore, voltage at point C is high (i.e., 5 V). In other words, when input is low the output is high and vice-versa.

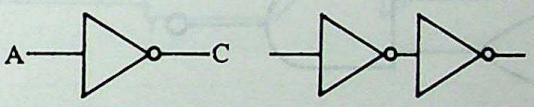
It is obvious from the above that a NOT gate inverts (i.e., converts a high input into a low output and vice-versa) the input voltage. This is the reason this gate is also referred to as a *inverter*. The truth-table of a NOT gate is

Input	Output
A	C
0V	5V
5V	0V

OR

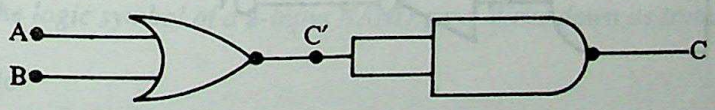
A	B
0	1
1	0

Fig. (a) below shows the standard logic symbol for an inverter. Fig. (b) shows cascaded inverters.



Q.182. *The output of an OR gate is connected to both the inputs of a NAND gate. Draw the logic circuit of this combination of gates and write the truth table.* **(3)**

Ans. Fig. below shows the logic circuit. Since, both input terminals of NAND gate are joined together, it works as a NOT gate. The whole arrangement, is equivalent to a NOR - gate. The truth-table is



A	B	C′	C
0	0	0	1
1	0	1	0
0	1	1	0
1	1	1	0

Q.183. *The output of an AND gate is connected to both inputs of a NAND gate. Draw the logic circuit of this combination of gates and write its truth table.* **(3)**

Ans. Fig. below shows the logic circuit. The NAND gate works as a NOT gate. The truth-table is

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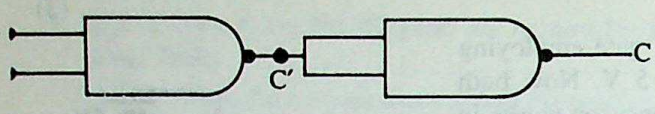
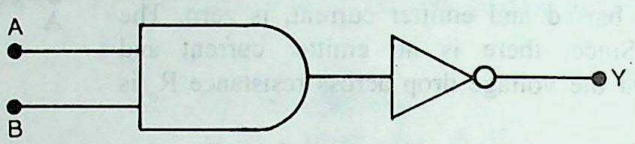


A	B	C'	C
0	0	0	1
1	0	0	1
0	1	0	1
1	1	1	0

Q.184. *Write the truth table for the combination of gates shown below.*

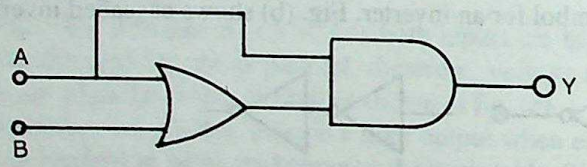


Ans. **(CBSE 1997)** (1)

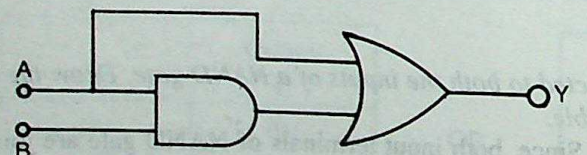
A	B	Y
0	0	1
1	0	1
0	1	1
1	1	0

Q.185. *Write the truth table for the following combination of gates:*

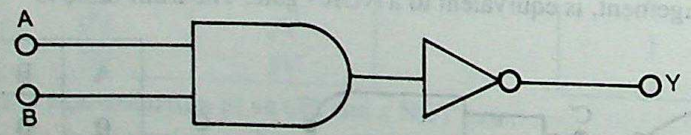
(a)



(b)



(c)



Ans. (a) **(CBSE 1998)** (1)

A	B	Y
0	0	0
1	0	1
0	1	0
1	1	1

(b)

A	B	Y
0	0	0
1	0	1
0	1	0
1	1	1

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(c)

A	B	Y
0	0	1
1	0	1
0	1	1
1	1	0

Q.186. *The output of a two input NAND gate is fed to a NOT gate. Write down the truth table for the final output of the combination.* **(CBSE 1999) (2)**

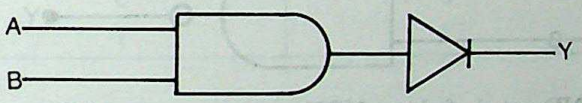
Ans. The final gate will act as a AND gate whose truth table is given below.

A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

Q.187. *The output of a 2 input AND gate is fed to a NOT gate. Draw the logic circuit of the combination of ates. Give its logic symbol and write its truth table. Identify the new logic gate formed.*

(CBSE 1997 Comptt.) (3)

Ans. The combination acts as NAND gate, whose logic symbol is given below:



Truth table :

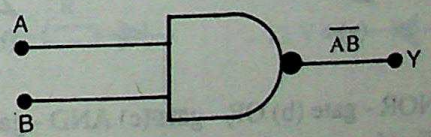
A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

Q.188. *Draw the logic symbol of a 2-input NAND gate. Write down its truth table.*

(CBSE 2000) (2)

Ans. Truth table

A	B	Y
0	0	1
1	0	1
0	1	1
1	1	0



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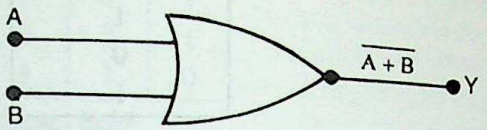
Q.189. *Draw the logic symbol of a 2-input NOR gate. Write down its truth table.* **(CBSE 2000) (2)**

Ans. Truth table:

A	B	C
0	0	1
0	1	0
1	0	0
1	1	0



Q.190. *The following truth table gives the output of a 2-input logic-gate.*

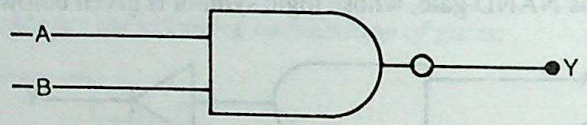
A	B	Output
0	0	1
0	1	1
1	0	1
1	1	0

(i) Identify the logic gate used and draw its logic symbol.

(ii) If the output of this gate is fed as input to a NOT gate, name the new logic gate so formed.

(CBSE 2000) (2)

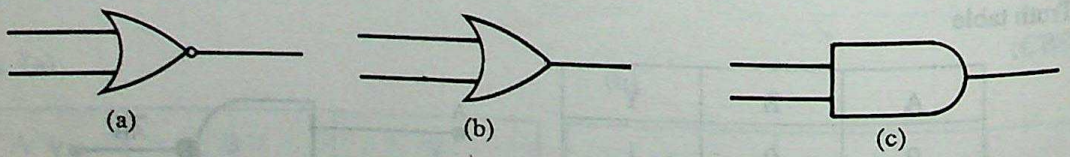
Ans. (i) The logic gate used is NAND gate. Its logic symbol is given below:



(ii) When the output of NAND gate is fed to a NOT gate, we get an AND gate.

A	B	Output of NAND gate	Output of NOT gate
0	0	1	0
0	1	1	0
1	0	1	0
1	1	0	1

Q.191. *Identify the gates corresponding to the symbols shown below.*



Ans. (a) NOR - gate (b) OR - gate (c) AND - gate.

Q.192. *What happens when both the inputs of a NAND gate are connected together?* **(1)**

Ans. NAND gate works as a NOT-gate

Q.193. *Three NAND gates are connected together as shown in figure. Show that the combination is equivalent to an OR gate.*

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Ans. The truth-table of given arrangement is

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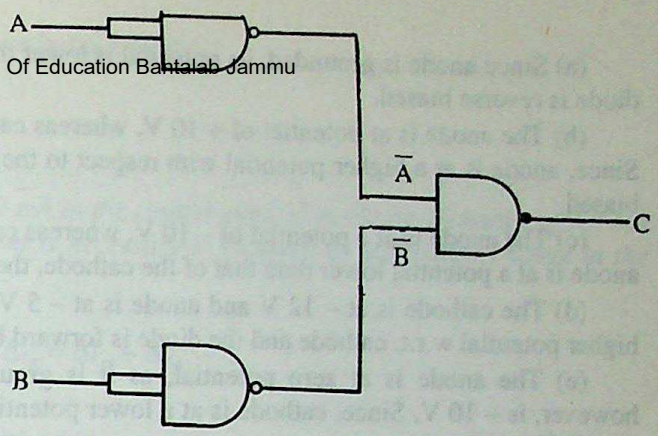
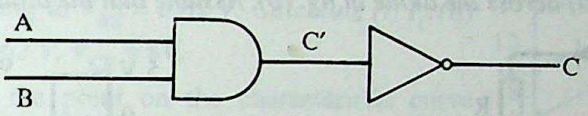
A	$\overline{A}$	B	$\overline{B}$	C
0	1	0	1	0
1	0	0	1	1
0	1	1	0	1
1	0	1	0	1



Looking at A, B and C in truth table it is obvious that the arrangement has same truth table as that of an OR-gate.

Q.194. *The output C′ of an AND gate is used as the input of a NOT gate as shown in figure. Show that the final output C will be the same as would be obtained by applying the inputs A and B to "NAND" gate.* **(3)**



Ans. The truth-table of the given arrangement is given below:

A	B	C′	C
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0

The truth-table is same as that of NAND gate. Hence, the given arrangement is equivalent to a NAND gate.

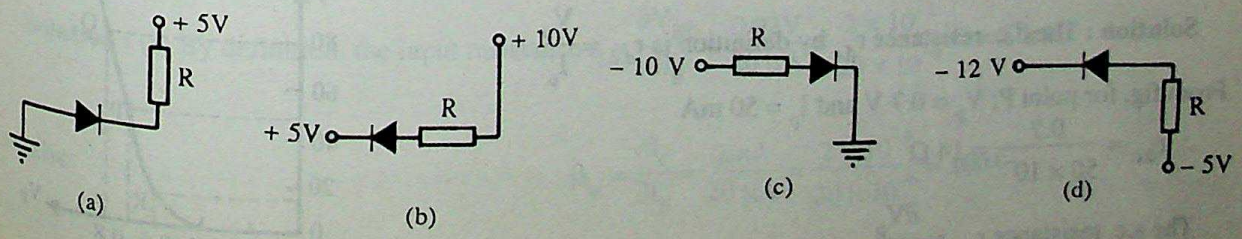
SOLVED NUMERICAL PROBLEMS ON UNIT – XII

Example 1. *Pure silicon at 300 K has equal electron and hole concentrations of* $1.5 \times 10^{16}/m^3$. *Doping by indium, increases the hole concentration to* $4.5 \times 10^{22}/m^3$. *Calculate the new electron concentration in the doped silicon.* **(CBSE 1997 Comptt.)**

Solution: $n_i = 1.5 \times 10^{16}/m^3$, $n_h = 4.5 \times 10^{22}/m^3$.

Now, $n_i^2 = n_e n_h \Rightarrow n_e = \dfrac{n_i^2}{n_h} = \dfrac{(1.5 \times 10^{16})^2}{4.5 \times 10^{22}} = 5 \times 10^9/m^3$.

Example 2. *In the fig. below which of the diodes are forward biased and which are reverse.*



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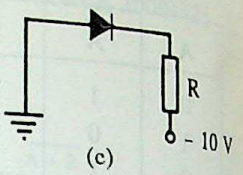
(a) Since anode is grounded, its potential is lower than that of the cathode and the diode is reverse biased.

(b) The anode is at potential of + 10 V, whereas cathode has a potential of +5 V. Since, anode is at a higher potential with respect to the cathode, the diode is forward biased.



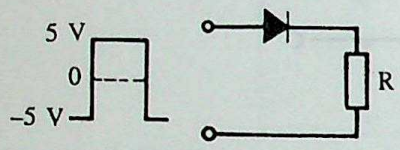
(c)

(c) The anode is at a potential of – 10 V, whereas cathode is a 0V potential. Since anode is at a potential lower than that of the cathode, the diode is reverse biased.

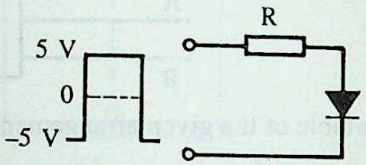
(d) The cathode is at – 12 V and anode is at – 5 V. The anode is, therefore, at a higher potential w.r.t. cathode and the diode is forward biased.

(e) The anode is at zero potential, as it is grounded. The cathode potential, however, is – 10 V. Since, cathode is at a lower potential w.r.t. to anode, the diode is forward biased.

Example 3. *In fig. below if the input wave form is as shown what will be the output waveform, (i) across R in fig. (a) and (ii) across the diode in fig. (b). Assume that the diode is ideal.*

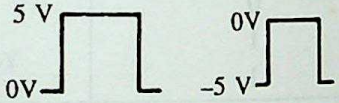


(a)



(b)

Solution : (a) When the given wave form is applied, the anode is at a potential of – 5V and it is reverse biased. The diode does not conduct. This continues till the input signal acquires a voltage of zero volt. In other words, the output across diode is zero when input varies from – 5 to 0 volt. As the input voltage increases beyond zero volt, the diode becomes forward biased and starts conducting and the pulse passes. The waveform across diode, therefore, is as shown in fig. alongside.



(b) When input signal voltage is varying from – 5 V to 0 V, the diode does not conduct and the entire voltage appears across resistance. As soon as the diode starts conducting, the voltage across resistance drops to zero. The wave form across resistance, therefore, is as shown in fig. alongside.

Example 4. *When the voltage drop across a p-n junction diode is increased from 0.65 V to 0.70 V, the change in the diode current is 5 mA. What is the dynamic resistance of the diode.* **(CBSE 1994)**

Solution : The dynamic resistance $r_{a.c.} = \frac{\Delta V}{\Delta I}$

Give $\Delta V = 0.7 - 0.65 = 0.05$ V and $\Delta I = 5 \times 10^{-3}$ A

$\therefore r_{a.c.} = \frac{5 \times 10^{-2}}{5 \times 10^{-3}} = 10\ \Omega.$

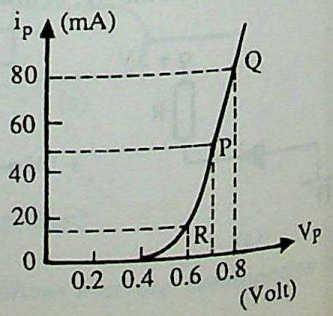
Example 5. *The characteristic curve of a diode is shown in fig. below. Determine the d.c. and a.c. resistance around point P.*

Solution : The d.c. resistance $r_{d.c}$ by definition is $r_{d.c.} = \frac{V_p}{I_p}$

From fig. for point P; $V_p = 0.7$ V and $I_p = 50$ mA

$\therefore r_{d.c.} = \frac{0.7}{50 \times 10^{-3}} = 14\ \Omega$

The a.c. resistance $r_{a.c.} = \frac{\partial V_p}{\partial I_p}$



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Around point P consider two points Q and R as shown in fig. Clearly,

$\partial V_p = 0.8 - 0.6 = 0.2$ V, $\partial I_p = (80 - 15) = 65$ mA

$$\therefore r_{a.c.} = \frac{0.2}{65 \times 10^{-3}}\ \Omega = \mathbf{3.07\ \Omega}.$$

Example 6. *In a silicon transistor, a change of 7.89 mA in the emitter current produces a change of 7.8 mA in the collector current. What change in the base current is necessary to produce an equivalent change in the collector current?*

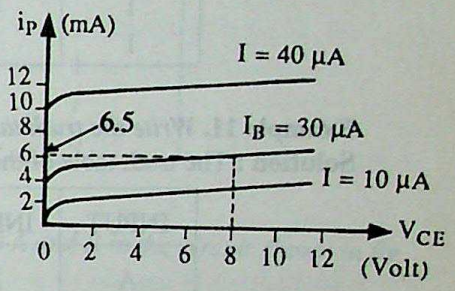
Solution : We know that

$$I_E = I_C + I_B \ \therefore\ \Delta I_E = \Delta I_C + \Delta I_B$$

Given $\Delta I_E = 7.89$ mA; $\Delta I_C = 7.8$ mA

$\therefore \Delta I_B = \Delta I_E - \Delta I_C = (7.89 - 7.8)$ mA $= 0.09$ mA $= \mathbf{90\ \mu A}$.

Example 7. *Fig. below gives the characteristic curves of a transistor which has $I_B = 30\ \mu A$ corresponding to $V_{BE} = 0.62$ V. Calculate (i) I_C (ii) I_E (iii) α and (iv) β. Give $V_{BE} = 0.62$ V, $V_{CE} = 8$V.*



Solution : (i) In fig. P is the point on the characteristic curve corresponding to

$I_B = 30\ \mu A$ and $V_{CE} = 8.0$ V

The collector current I_C, as read off from the given graph, is **6.5 mA.**

(ii) $I_E = I_C + I_B = 6.5 + 0.030 =$ **6.530 mA**

(iii) $\alpha = \dfrac{I_C}{I_E} = \dfrac{6.5}{6.530} = \mathbf{0.995}$

(iv) $\beta = \dfrac{\alpha}{1-\alpha} = \dfrac{0.995}{1-0.995} = \dfrac{0.995}{0.005} = \mathbf{199}$

Example 8. *The input resistance of a common emitter amplifier is 2kΩ and a current gain is 20. If the load resistance is 5kΩ, Calculate:*

(i) the voltage gain of the amplifier.

(ii) the transconductance of transistor used. **(CBSE 1999)**

Solution: $R_i = 2\ k\Omega = 2000\Omega$, $\beta = 20$, $R_L = 5K\Omega = 5000\ \Omega$

(i) Voltage gain $= \beta \dfrac{R_L}{R_i} = 20 \times \dfrac{5000}{2000} = \mathbf{50}$

(ii) Transconductance $= \dfrac{\text{Voltage gain}}{R_L} = \dfrac{50}{5000} = \mathbf{0.01\ \Omega^{-1}}$

Example 9. *In a silicon transistor, the base current is changed by 20 μA. This results in a change of 0.02 V in base to emitter voltage and a change of 2 mA in the collector current. (a) Find the input resistance, β_{ac} and transconductance of the transistor (b) The transistor is used as an amplifier with the load resistance 5 kΩ. What is the voltage gain of the amplifier?*

Solution : (a) By definition, the input resistance $r_i = \dfrac{\partial V_{BE}}{\partial I_B} = \dfrac{0.02\text{V}}{20\ \mu\text{A}} = \dfrac{2 \times 10^{-2}}{20 \times 10^{-6}}\ \Omega = \mathbf{1\ k\ \Omega}$

Also

$$\beta_{ac} = \frac{\partial I_C}{\partial I_B} = \frac{2\text{mA}}{20\ \mu\text{A}} = \frac{2 \times 10^{-3}}{20 \times 10^{-6}} = \mathbf{100}$$

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The trans-conductance $g_m = \frac{\Delta I_C}{\Delta V_{BE}} = \frac{\beta_{a.c.}}{r_i} = \frac{100}{1000} = 0.1\ \Omega^{-1}$

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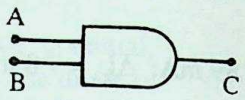
(b) The voltage gain A_v of amplifier is $|A_v| = g_m \times R_L = 0.1 \times 5000 = 500$.

Example 10. *Write the truth table for the AND gate.*

Solution : For the AND gate, the truth table is as shown below: (CBSE 1995)

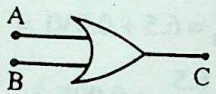
INPUT		OUTPUT
A	B	C
0	0	0
0	1	0
1	0	0
1	1	1



Example 11. *Write the truth table for 'OR' gate.* (CBSE 1994)

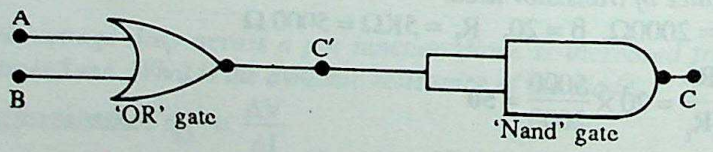
Solution : The truth table of the 'OR' gate is as follows :

INPUT	INPUT	OUTPUT
A	B	C
0	0	0
0	1	1
1	0	1
1	1	1



Example 12. *The output of an OR gate is connected to both the inputs of a NAND gate. Draw the logic circuit of this combination of gates and write the truth table.* **(CBSE 1994 Comptt.)**

Solution : The required logic circuit is shown below.



The *truth table* is given below:

A	B	C′	C
0	0	0	1
0	1	1	0
1	0	1	0
1	1	1	0

The combination, thus, works as a NOR gate.

Example 13. *The output of an AND gate is connected to both the inputs of NAND gate. Draw the logic circuit of this combination of gates and write its truth table.*

(CBSE 1994 Comptt.)

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Solution : The required logic circuit is shown below.

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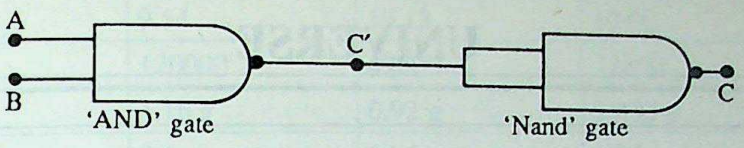
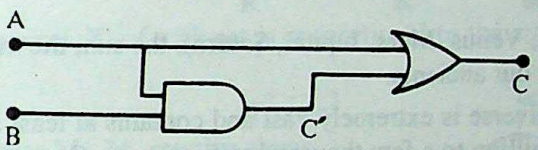


The truth table is given below :

A	B	C′	C
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0

The combination, thus, acts like a NAND gate.

Example 14. *Express in a truth-table the output C for all possible inputs A and B in the circuit shown in fig. below.*



Solution : Inputs A and B are given to AND gate. C′ is written using truth table of AND gate. The second gate is OR gate. The input for gate is A and C′. Using truth table of OR gate the output C is obtained. This is summarised in the table given below:

A	B	C′	C
0	0	0	0
0	1	0	0
1	0	0	1
1	1	1	1

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UNIT – XIII

UNIVERSE

CBSE SYLLABUS CONTENTS

The constituents of the universe; planets — elementary idea about determination of their distances and masses. Stars — brightness, magnitude scale, luminosity, surface temperature; energy source of stars (concept only).

No. of periods allotted : 7 out of 168

No. of marks allotted : 3 out of 70.

BASIC FACTS AND FORMULAE

The Constituents of the Universe

1. The five planets (Mercury, Venus, Mars, Jupiter, Saturn), the sun, the moon, the fixed stars and the earth constituted the entire universe for our ancients.

2. We now know that the universe is extremely vast and contains at least a thousand million galaxies each containing from a few hundred million to a few thousand million stars. Our sun is but one such star in one such galaxy the milky way galaxy.

3. The solar system consists of the sun, nine planets with their associated moons, thousands of asteriods, meteors and a few comets.

4. The nine planets of the solar system have been divided into two broad categories – the *inner* planets and the *outer* planets depending on their distances from the sun. There is a sharp differences in the characteristics of these two groups of planets.

5. The four *inner* planets are : Mercury, Venus, Earth and Mars while the five outer planets are : Jupiter, Saturn, Uranus, Neptune and Pluto.

6. The asteroids, meteors and the comets are considered as *minor* bodies in the solar system.

Data about the Solar System

4. Table 1. list the distances from the sun and the sizes of the various planets of the solar system and their surface gravities and masses.

Table 1 : Distance from sun & size of various planets.

Name of the member	Mercury	Venus	Earth	Mars	Jupiter
Period in (earth) year	0.241	0.615	1.000	1.8808	11.86
Distance (in A.U.)	0.387	0.723	1.000	1.524	5.20
Diameter (in km.)	800	12160	12800	6720	140080
Surface gravity	0.37 g	0.9 g	1 g	0.4 g	2.64 g
Mass	0.05 m_e	0.22 m_e	1 m_e	0.11 m_e	318 m_e

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Name of the member	Saturn	Uranus	Neptune	Pluto
Period in (earth) year	29.46	84.01	164.79	248.43
Distance (in A.U.)	9.54	19.18	30.00	39.52
Diameter (in km.)	120000	49600	52800	6400
Surface gravity	1.16 g	0.92 g	1.435 g	0.44 g
Mass	9.5 m_e	14.6 m_e	17.2 m_e	0.1 m_e

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Some Quantitative Results

1. When an object of diameter 'd' is at a distance 'R' from an observation point, its 'angular diameter', θ is given by $\theta = d/R$

2. When an object of mass m revolves about a central massive object of mass M in an orbit of radius r, we have $\frac{mv^2}{r} = \frac{GMm}{r^2}$ or $v^2 = \frac{GM}{r}$

But $v = 2\pi r/T$ $\therefore$ $\frac{4\pi^2 r^3}{T^2} = GM$ or $M = \frac{4\pi^2 r^3}{GT^2}$

We may use this relation to determine 'M'.

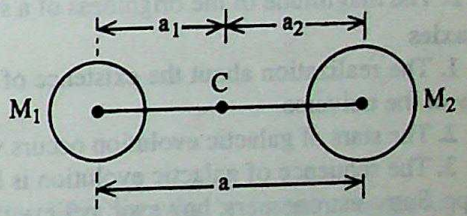
3. The acceleration due to gravity, g, is related to 'G'. by

$$mg = \frac{GMm}{R^2} \text{ or } r = \frac{GM}{R^2}$$

4. The square of the time period, T, of a planet is proportional to the cube of the semi major axis, a, of its elliptical orbit.

$$T^2 \propto a^3$$

5. When two objects of masses M_1, M_2 revolve about their common centre of mass with a period T, the following relations hold good :



$$M_1 a_2 = M_2 a_2 \text{ and } M_1 + M_2 = \frac{4\pi^2}{G}\frac{a^3}{T^2}$$

$$a = a_1 + a_2$$

Albedo and Surface Temperature of a Planet

8. The *albedo* of a planet is indicative of its *reflection coefficient.*

9. If L be the luminosity of a planet, A its albedo and T is surface temperature, we have

(i) total energy absorbed by the planet $= \frac{(1 - A)\, Lr^2}{4d^2}$

(r = radius of the planet, d = radius of the planetary orbit).

(ii) surface temperature 'T' of the planet is given by

$$\sigma T^4 \cdot 4\pi r^2 = (1 - A)\, L \frac{r^2}{4d^2} \quad (\sigma = \text{Stefan's constant})$$

or $$T = \left[\frac{(1 - A)\, L}{16\pi\sigma d^2}\right]^{1/4}$$

Some Basic Facts about Stars

1. Astronomers have now learnt how to estimate the mass, size, temperature and chemical composition of different stars. They have also learnt about the energy sources of stars, their birth, evolution and death.

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2. Stars are classified in terms of the magnitude of their brightness. A brightness ratio of 100 is now taken to represent 5 magnitudes of brightness difference.

3. In terms of their spectra, stars have been classified as *O, B, A, F, G, K* and *M* stars.

4. A star is born when a cloud of interstellar dust and gas of mass more than a thousand times than that of the sun begins to contract under its own gravitation.

5. The stars release their energy through thermonuclear reactions or nuclear fusion. This involves the fusion of four hydrogen atoms to form one helium nucleus.

6. A star continues to 'live' until its hydrogen stock gets exhausted. At this stage, there is a drop in its surface temperature when an ultimate explosion throws out most of the outer stellar matter in space, the original star is said to have died.

7. In terms of the stage of their evolution, stars are known as :

(i) Dwarf stars, (ii) Giants or supergiant stars,

(iii) Nova or super (iv) Dark stars, nova,

(v) Neutron stars, (vi) Pulsars, and

(vii) Black holes.

8. We speak of many star constellation in the sky and these have served as sources of legends and superstitions.

9. The distances of stars are measured by the triangulation method (using stellar parallaxes) while a study of binary star systems was used to estimate stellar masses by using Kepler's third law.

Luminosity and Absolute Magnitude of a Star

1. The luminosity of a star depends on its mass and nearly as the 7/2 power of the mass.

2. The magnitude of the brightness of a star at a distance of 10 parsec is known as its absolute magnitude.

Galaxies

1. The realization about the existence of galaxies and a measurement of their dimensions have changed our view of the universe.

2. The stars of galactic evolution occurs when billions of stars *condense* into a huge quantity of gas.

3. The sequence of galactic evolution is believed to be from spheriodal to elliptical to spiral arm to irregular shape. Some astronomers, however, believe the order to be the reverse of this one.

Pulsars, Quasars and B.S.O.

1. Pulsars are very tiny but extremely dense neutron stars emitting pulses (mostly in the microwave region) at regular intervals varying from about 30 millisecond to about 3 second. Attempts to understand their nature has helped to have a better understanding of the universe.

2. Quasars (or quasi-stellar objects) are the galactic analognes of the pulsars. They were discovered by using radio telescopes.

3. It has been estimated that quasars may be anywhere from thirty to hundred times as luminous as an ordinary galaxy.

4. The discovery of blue stellar objects or B.S.O.'s, is regarded as a big blow to the steady state theory of the universe.

The Stefan's Law and the Wien Displacement Law

According to Stefan's law, the energy E radiated by an area A of a black body at temperatures T is given by

$$E = \sigma A T^4$$

According to Wien's law, we have $\lambda_m T =$ constant, where $\lambda_m =$ wavelength of the maximum emission, T = temperature of the body

The Magnitude of a Star

1. The magnitude of a star is indicative of its relative brightness. The ratio of the brightness of two stars of successive magnitudes is 2·512 : 1, $\frac{\text{Brightness of a star of magnitude 'n'}}{\text{Brightness of a star of magnitude (n + 1)}} = \frac{2{\cdot}512}{1}$

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2. Since $(2.512)^5 = 100$, the brightness of a star decreases by a factor of 100 when its magnitude increases by 5.

3. $\frac{\text{Brightness of a star of magnitude } m_1}{\text{Brightness of a star of magnitude } m_2} = (100)^{(m_2 - m_1)/5}$.

4. If I_1 and I_2 are the intensities of the star of magnitudes m_1 and m_2, we have

$$\frac{I_1}{I_2} = (100)^{(m_2 - m_1)/5} \text{ or } \log\left(\frac{I_1}{I_2}\right) = \frac{(m_2 - m_1)}{5} \cdot \log 100 = 0.4\,(m_2 - m_1)$$

$$\therefore \log\left(\frac{I_2}{I_2}\right) = -0.4\,(m_2 - m_1).$$

5. If I and I_0 are the intensities of a star of magnitude zero, we have $m = -2.5 \log (I/I_0)$.

Doppler's Red Shift and Hubble's Law

1. The Doppler shift formula for light is $\left|\frac{\Delta\lambda}{\lambda}\right| = \frac{v}{c}$

2. According to Hubble's law :

The velocity of recession of a galaxy increases in proportion to its distances from the galaxy : velocity = H × distance, where H is known as Hubble's constant.

H is expressed in units of (km/s)/mega per s.

Theories Regarding to Origin of the Universe

The three main theories regarding the origin of the universe are :

(i) The *big-bang* theory,

(ii) The *steady-state* theory and

(iii) The *pulsating* universe theory.

India's Achievements in Space

India has had quite a good 'track record' in space. The following table lists the 'milestones' achieved by India in the field of its space programme.

India's Achievements in Space

Date	Satellite	Launched by	Result
March 19,1975	Aryabhatta	USSR	Success
June 7, 1979	Bhaskara-I	USSR	Success
Aug 10, 1979	Rohini	India, SLV-3	Failure
May 31, 1981	Rohini	India, SLV-3	Failure
July 18, 1980	Rohini	India, SLV-3	Success
June 19, 1981	Bhaskara-II	USSR	Success
Nov 20, 1981	Bhaskar II	USSR	Success
April 17, 1983	Rohini	India SLV-3	Success
	Apple	European Space Agency	Success
March 24, 1987	SROSS-I	India, ASLV	Failure
March 19, 1988	IRS-1A	USSR	Success
July 13, 1988	SROSS-II	India, ASLV	Failure
Aug 29, 1991	IRS - IB	USSR	Success
May 20, 1992	SROSS-III	India, ASLV	Success
July 10, 1992	INSAT-2A	Kourou (South America)	Success

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July 23, 1993	INSAT-2B	France	Success
Sept. 29, 1993	INSAT-1E	India (P. SLV-D_1)	Unsuccessful
Oct. 15, 1994	IRS-P2	India (P. SLV-D_2)	Success
Dec. 7, 1995	INSAT-2C	Kourou (South America)	Success
Dec. 28, 1995	IRS-1C	Kazakhstan	Success
March 21, 1996	IRS-P-3	India (PSLV-D_3)	Success
June 4, 1997	INSAT-2D	Kourou	Unsuccessful
Sept 29, 1997	IRS-1D	India (P.SLV-C_1)	Success
May 26, 1999	IRS-P-4	India (P.SLV-C_1)	Success
May 26, 1999	Two Foreign Satellites		
	Tubsat - (German)	India (P.SLV-C_2)	Success
	Kitsat-(S.Korean)		
March 22, 2000	INSAT-3B	Kourou	Success

SUBJECTIVE QUESTIONS ON UNIT – XIII

Q.1. *What is astronomy?* (1)

Ans. Astronomy is a branch of science concerned with the study of the position, nature, composition, temperature, etc., of the planets, stars and other 'heavenly bodies'.

Q.2. *What is astronomical unit?* (1)

Ans. The astronomical unit is a unit of distance used in astronomy. It equals the distance between the earth and the sun. We have $1AU = 1{\cdot}496 \times 10^{11}$ m $= 1.496 \times 10^{8}$ km.

Q.3. *What is one light year?* (1)

Ans. One light year equals the distance covered by light, in vacuum, in a time equal to one year. We have

1 light year $\approx (3 \times 10^8) \times (365 \times 24 \times 60 \times 60)$ m $= 9.46 \times 10^{15}$ m $= \mathbf{9.46 \times 10^{12}}$ **km.**

Q.4. *What is a parsec?* (1)

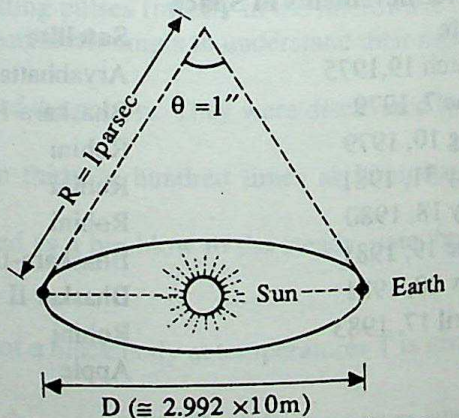
Ans. The *parsec* is also a unit of distance used in astronomy. It is the distance at which the two diametrically opposite points, of the earth's orbit around the sun, subtend an angle of one second of arc. We, thus, have

$$\frac{D}{1 \text{ parsec}} = 1'' = \left(\frac{1}{60 \times 60}\right)^0 = \left(\frac{1}{3600} \times \frac{\pi}{180}\right) \text{radian}$$

$$\therefore 1 \text{ parsec} = \frac{D \times 60 \times 60 \times 3600 \times 180}{\pi} \text{ m}$$

$$= \frac{2.992 \times 10^{11} \times 36 \times 36 \times 18 \times 10^5}{\pi} \text{ m}$$

$$\approx \mathbf{30.3 \times 10^{15}} \text{ m.}$$



Diameter of earth's orbit around the sun

Q.5. *How many light years equal one parsec?* (1)

Ans. 3.25 light years = 1 parsec

Q.6. *Name the galaxy of which the solar system is a part.* (1)

Ans. The solar system is a part of the *Milky way galaxy.*

Q.7. *What is Milky way?* (1)

Ans. The Milky way galaxy is a visible white shining streak of light seen in the middle of the sky on a clear cloudless dust free dark night. It is made up of a very large number of stars.

Q.8. *What is the approximate distance of the sun from the centre of the Milky way?* (1)

Ans. The sun is at a distance of nearly 3×10^4 light years from the centre of the milky way galaxy.

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Q.9. *Name the galaxy closest to the Milky way.* **(1)**

Ans. The galaxy, closest to the milky way galaxy, is the *Andromeda Nebula.*

Q.10. *What is the approximate number of stars constituting the Milky way?* **(1)**

Ans. There are approximately 10^{11} stars in the Milky way galaxy.

Q.11. *What is a constellation?* **(2)**

Ans. A constellation is a group of stars arranged in such a way in a sky that their collections appears to resemble the form of some god,, legendary figure or animal, etc.

Q.12. *What are asteroids? Where are they found?* **(2)**

Ans. Asteroids are irregularly shaped bodies that are a part of the solar family. They are found in large numbers between the orbits of Mars and Jupiter and range in size from a few 100 m in diameter to about a few hundred kilometer.

Q.13. *Name the largest asteroid in the solar system.* **(1)**

Ans. One of the largest asteroids of the solar system is *Ceres.* Its diameter is about 500 km.

Q.14. *What are comets?* **(2)**

Ans. Comets are large heavenly bodies moving around the sun in highly elliptical orbits. They are composed mainly of water, ammonia methane and metallic dust. They also develop a 'tail' when they come close to the sun.

Q.15. *What are comets composed of?* **(CBSE 1993) (1)**

Ans. Comets are composed of very loosely packed gaseous matter.

Q.16. *How do comets form tails?* **(CBSE 1992) (2)**

Ans. The loosely packed gaseous matter, making up the comets get attracted towards the sun by its strong gravitational field.

Q.17. *Why comets develop a tail as they come close to the sun?* **(2)**

Ans. The comets are made up of gases whose molecules are close together and very loosly bound. They experience a strong gravitational force when they are close to the sun. It is this gravitational force that results in the appearance of a 'tail' around them.

Q.18. *Why does a comet not have a tail when it is far off from the sun?* **(2)**

Ans. Since the 'tail' is due to the strong gravitational attraction of the sun, there is no such tail when the comets are far off from the sun.

Q.19. *What are periodic comets? Name a periodic comet of the solar system?* **(2)**

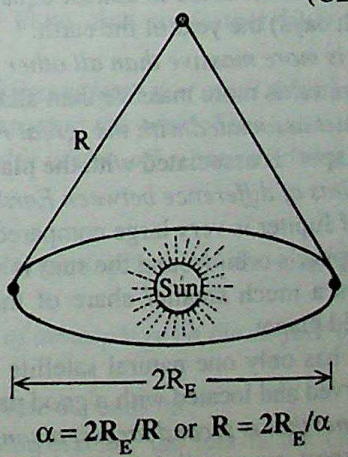
Ans. Periodic comets are those comets that keep on reappearing in the solar system after regular time intervals. One of the best known periodic comets is the *Halley's Comet* that has a period of nearly 76 years. It was last seen in 1986 and is expected again in 2062.

Q.20. *What are meteors?* **(CBSE 1994 Comptt.) (2)**

Ans. Meteors are pieces of matter and metal that keep on entering the earth's atmosphere from the outer space.

Q.21. *Outline the 'parallax method' for determination of the distance of planet from the earth.* **(CBSE 1994 Comptt.) (2)**

Ans. The planet's position is observed from two points on the earth's orbit around the sun. The observations are taken against the background of the fixed stars. If this parallax angle is α, we have



$\alpha = 2R_E/R$ or $R = 2R_E/\alpha$

Knowing E_E and α, we can calculate R.

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Q.22. *Explain why meteors are visible?* (2)

Ans. The meteors enter to Earth's atmosphere with very high velocities. As a result, there is tremendous friction between them and the atmospheric layers and this results in the production of a very large amount of heat. This heats up the meteors to high temperatures and they become visible.

Q.23. *Name the nine planets in order of their increasing distance from the sun.* (2)

Ans. The nine planets, in order of their increasing distance from the sun, are : Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto.

Q.24. *What is the approximate surface temperature of the sun?* (1)

Ans. The surface temperature of the sun is about 5800 K.

Q.25. *Name the nearest (to the sun) planet in the solar system.* (1)

Ans. The planet, nearest to the sun, is *Mercury.*

Q.26. *Name the farthest (from the sun) planet in the solar system.* (1)

Ans. The planet, farthest from the sun, is *Pluto.*

Q.27. *Name the planet having the smallest period of revolution about the sun. Give its time period in terms of earth year.* (1)

Ans. The planet Mercury has the smallest period of revolution around the sun. It completes one revolution, around the sun, in about 0.241 earth years, i.e., nearly 88 earth days.

Q.28. *Name the planet having the largest period of revolution about the sun. Give the time period in terms of earth year.* (1)

Ans. The planet Pluto has the largest period of revolution around the sun. It completes its one orbit in nearly 248.43 earth years.

Q.29. *Name the planet having a distance from the sun approximately 20 times the distance of earth from the sun.* (1)

Ans. The distance of the planet Mars, from the sun, is nearly 20 times the distance of the earth from the sun.

Q.30. *Name the four inner planets.* (1)

Ans. The four planets. Mercury, Venus, Earth and Mars are known as the four inner planets.

Q.31. *Write the names of any two superior planets.* **(CBSE 1993 Comptt.)** (1)

Ans. Earth and Venus.

Q.32. *Name the two planets that are referred to as the 'morning' and the 'evening' stars.* (1)

Ans. The planets Earth and Venus are known as the morning and the evening stars.

Q.33. *One of the inner planet has its 'day' longer than its 'year'. Name this planet.* (1)

Ans. The 'day' of the planet Venus is longer than its 'year'.

Q.34. *Name the planet that was supposed to have some sort of life on it.* (1)

Ans. The planet 'Mars' was, at one time, believed to have some sort of life on it.

Q.35. *How do the 'day' and the 'year' of Mars compare with those of the earth?*

Ans. The 'day' of the planet Mars is almost equal to that of Earth (~ 24.5 Earth hours) while its 'year' is nearly 2 times (687 Earth days) the year of the earth.

Q.36. *Which planet is more massive than all other planets combined?* (1)

Ans. The planet 'Jupiter' is more massive than all the other planets combined.

Q.37. *Name the planet associated with the 'great red spot'.*

Ans. The 'great red spot' is associated with the planet Jupiter.

Q.38. *Write four points of difference between Earth and Jupiter.* **(CBSE 1996)**

Ans. (i) The mass of Jupiter is very large compared to that of the earth.

(ii) The radius of Jupiter's orbit (round the sun) is very large compared to that of the earth.

(iii) Jupiter receives a much smaller share of the solar energy compared to the earth and is, therefore, comparatively a very cold planet.

(iv) Whereas Earth has only one natural satellite (the moon), Jupiter has 16 such satellites. Of which the largest four can be observed and located with a good pair of binoculars.

Q.39. *Name the planet that is second largest among all the planets.* (1)

Ans. The second largest, among all the planets, is the planet '*Saturn*'.

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Q.40. *Name the hottest and the coldest planet in the solar system.*

Ans. Pluto is the coldest and Venus is the hottest of all the planets. Their surface temperatures are nearly 33 K and 750 K respectively. **(1)**

Q.41. *Which characteristic of saturn is different from that of any other planet?*

Ans. Saturn is characterized by its unique system of rings around. it. There are no such rings with any other planet. **(1)**

Q.42. *Give the number of moons associated with saturn.*

Ans. Saturn has as many as 17 'moons' associated with it. **(1)**

Q.43. *What can we say about the relative sizes of Uranus and Neptune?*

Ans. Uranus and Neptune are so nearly close in size that they are often referred to as 'twins'. **(1)**

Q.44. *Name the planet of the solar system having the largest size.*

Ans. The largest planet in the solar system is Jupiter. **(1)**

Q.45. *Do planet of the solar system rotate about their own axis?*

Ans. Yes, the planets of the solar system rotate about their own axis in addition to their revolution around the sun.

Q.46. *What is the relation between the rotation of earth and Venus about their own axis?*

Ans. Unlike earth, (which rotates from west to east about its own axis), the planet Venus rotates from east to west about its own axis. Thus, Venus's rotation about its own axis is opposite in sense to the rotation of the earth about its own axis. **(1)**

Q.47. *Name the planet of the solar system having the largest surface gravity.*

Ans. The planet Jupiter has the largest surface gravity. The surface gravity of this planet is nearly 264 times the surface gravity of the earth. **(1)**

Q.48. *Name the planets of the solar system having no moons.*

Ans. The planets Mercury, Venus and Pluto do not have any moons associated with them. **(1)**

Q.49. *Name the planet of the solar system having largest number of moons.*

Ans. The planet *Saturn* has the largest number of moons - 17 moons associated with it. **(1)**

Q.50. *Name the planet of the solar system having the smallest number of moons.*

Ans. The planet *Earth* has the smallest number (only one) of moons associated with it. **(1)**

Q.51. *Name the largest moon in the solar system.*

Ans. The largest moon, in the solar system, is the moon of the earth. **(1)**

Q.52. *Define solar constant and give its value.*

Ans. The solar constant equals the amount of radiant energy (of the sun) received by a unit area on the earth in a unit time, when that area is so oriented that the sun's rays fall normally on it. **(1)**

The value of the solar constant is nearly 1.388×10^3 Wm^{-2}.

Q.53. *What are Jovian planets?*

Ans. The four planets Saturn, Uranus, Neptune and Pluto, that are farther from the sun than the planet Jupiter, are known as the *Jovian planets*. **(1)**

Q.54. *What special characterstics of Pluto's orbit is different from that of all other planets?*

Ans. The orbit of Pluto is tilted by about 17 ° with respect to the orbit of the earth around the sun. No such 'tilt' is there is the orbit of the other planets. Further its orbit is also *off centered* so that, at times, it comes into the orbit of Neptune. **(1)**

Q.55. *What do you know about the planet 1992 Q BI?*

Ans. The '1992 QBI' has been talked off as a possible 'tenth planet' of the solar system. However, many astronomers are skeptical about its existence. **(2)**

Q.56. *Write two factors which determine the presence of atmosphere on the surface of a planet.*

(CBSE 1994) (2)

Ans. The presence of atmosphere on the surface of a plane depends on :

(i) The temperature of the planet (The higher the temperature, the less is the chance of its having an atmosphere).

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(ii) The surface gravity *(i.e.,* the acceleration due to gravity) of the planet. The more the surface gravity, the better is the chance of its having an atmosphere.

Q.57. *What is the meaning of the term albedo?* **(CBSE 1995 Comptt.)** (1)

Ans. The term 'albedo' implies the 'reflection coefficient' of a planet. Thus, the 'albedo' of a planet determines the fraction of the incident sunlight that is reflected by it.

Q.58. *Why has mercury no atmosphere?* (2)

Ans. The surface gravity of Mercury is rather small while its surface temperature is quite high. Both these factors are responsible for the non-existence of an atmosphere about this planet.

Q.59. *Moon has a low surface temperature yet it does not possess any atmosphere. Explain.* (2)

Ans. The surface gravity of moon is very low. Thus, inspite of its low temperature, the r.m.s. velocity of any gas molecules, if present there, would be still of the order of its escape velocity. The gas molecules, if any would, therefore, be easily able to escape from it and moon would not have any atmosphere.

Q.60. *Why is it said that pluto was once a moon of Neptune that has escaped into its own orbit?* (2)

Ans. The orbit of Pluto's is off centered and at times, it comes into the orbit of Neptune. Further, unlike the orbits of other planets, that of Pluto is tilted, about 17 ° with respect to the plane of the Earth's orbit around the sun. These 'unique' features of Pluto's orbit, coupled with its small size, have led some astronomers to suggest that Pluto might, at one time, have been a moon of Neptune that has now escaped into an orbit of its own.

Q.61. *What do you know about Halley's comet?* (2)

Ans. *Halley's comet* is a periodic comet that becomes 'visible' in the solar system, every 76 years. It was last seen during the years 1910 and 1986 and is now expected again in the year 2062.

It has been suggested that the periodic reappearance of comets-like Halley's comet - might be linked with the effect, of sun's gravity on them. The strong gravitational pull of the sun might be perturbing the orbits of these periodic comets and make them reappear at regular intervals.

Q.62. *What are the four different motions associated with earth? Give a brief account of the different layers of earth.* (3)

Ans. The Earth has four independent motions associated with it. These are :

(i) Its revolution round the sun in an elliptical orbit with the sun at one of the foci of the ellipse. As we know, this revolution is completed in nearly 365.26 'days' or one 'year'.

(ii) Its rotation about its own axis once in nearly 24 hours.

(iii) Its motion in the Milky Way Galaxy along with the sun a member of the solar family.

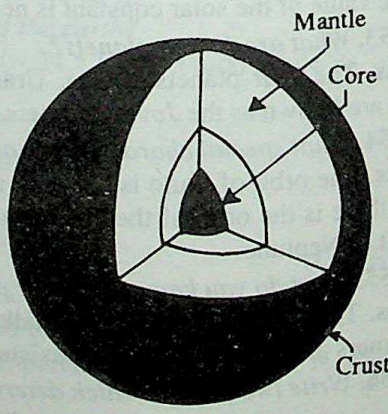
(iv) Its motion in space as a part of the overall motion of the Milky Way galaxy itself in space.

All these four independent motions give interesting 'effects' on the Earth.

A detailed study of Earth has revealed that we can consider it as made up of three parts : the Core, the Mantle and the Crust.

The Core is the innermost part of the Earth and is believed to be made up almost 90% of metallic iron and possibly silicon in the ratio 3 : 2. The remaining 10% of the core is believed to be made up of nickel mainly in the fluid state. The inner parts of the core are under a huge pressure of nearly 3.7 million atmosphere and have a temperature of the order of 5500 °C. Because of the huge pressure present in the inner core, the iron present there is in the solid form in spite of a temperature of nearly 5500°. The pressure goes down in the outer part of the core and the iron present there is, therefore, in the liquid state.

The middle layer of the Earth is known as the Mantle; this is believed to extend to nearly 2900 km below the Crust. The Mantle is believed to be made up mainly of oxygen, magnesium and silicon along with a small percentage of iron.



Various layers of the Earth

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The outermost 'thin' layer of the Earth is known as its Crust. It is on the crust that the oceans and continents are situated. The crust's thickness is believed to vary from 16 to 60 km, being thicker below the continents than below the oceans. The crust has a varying composition. At places, it is made up of light coloured rocks, like granite that are rich in silica, alumina and alkalis. At other places, it is made up of dark coloured rocks rich in iron oxide and magnesia.

Q.63. *Give a detailed account of the essential features of the four inner planets.* **(3)**

Ans. The four inner planets are : Mercury, Venus, Earth and Mars.

(i) **Mercury :** Mercury is the planet nearest to the sun. Radius of mercury's orbit around sun is $\left(\frac{2}{5}\right)^{th}$ of the radius of the earth around the sun. It is the smallest and the fastest of all the planets. Mercury can be seen for a short time just after sunset or before sunrise. Mercury is at a great distance from the earth.

We believe that mercury has no atmosphere. It is barren and rugged. Its surface temperature various from $+340^\circ$ C during day to -120° at night.

(ii) **Venus :** Venus is a planet known as twin of earth. It is almost of same radius, density and mass as earth. But for moon, Venus is the brightest object seen at night. Venus is covered by a thick cloud of gases containing about 95% CO_2. Surface temperature of Venus is about 480 °C. We have good reasons to believe that no life exists on Venus.

(iii) **Mars :** Mars has a mass nearly 1/10 of the mass of the earth. Its size is nearly half that of earth. Mars completes one revolution around sun in 1.88 earth year. It completes one revolution about its own axis in almost one earth day. Mars has red soil like colour and yellow clouds with polar caps. The polar caps grow larger during winter and become smaller in summer. Day temperature of Mars varies from 5 °C to 150 °C. Since conditions at Mars are very much similar to that on earth there is a strong possibility of existence of life on Mars.

For discussion on 'Earth', refer to answer no. 62.

Q.64. *Give a brief account of the different 'minor bodies' present in the solar system.* **(3)**

Ans. Besides the sun and the nine planets (along with their respective moons); there are some minor bodies in the solar system. These are : the asteroids, the meteors and meteorites and the comets. We now give the main features of these minor bodies.

The **asteroids** or minor planets are present throughout the solar system but their population is maximum in a belt between the orbits of Mars and Jupiter. As many as 40,000 asteroids have been identified with about 1000 of them having diameters of the order of 50 km or more. Ceres is the largest among the asteroids with a diameter of about 800 km.

Meteors or 'shooting stars' are rocky bodies floating around in space. We can also regard them as asteroids whose eccentric orbits bring them into collision with the earth. They are usually very small in size and are invisible until they strike the earth's atmosphere.

Because of the intense heat produced by friction (between a fast approaching meteor and the atmosphere) the meteor usually gets vaporised and very little of its 'remains' reach the earth. However, some meteors are large enough to survive the atmosphere and some of their 'still reasonably large' fragments manage to reach the Earth. We call such large enough meteors as **meteorities.**

Comets may be between 48000 and 240000 km in diameter. They are, however, made of a cloud of particles of stone, ice and various chemical crystals. However, the particles are so widely scattered that even the largest of comets is unlikely to contain as much matter as the Earth. Comets are thus, very unsubstantial objects.

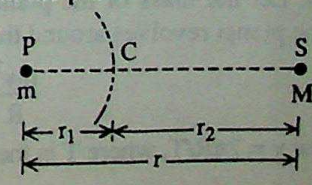
Q.65. *How do we estimate planetry distances and sizes? Give the relevant theory.* **(3)**

Ans. Let P and S denote a planet of mass m and the sun of mass M. PS = r is the distance of the planet from the sun. Let C be the centre of mass of the system. Taking point P as the origin of coordiante system and measuring distance along line PS, the distance r_1 of the centre of mass C from the planet P.

$$r_1 = \frac{m \times o + Mr}{m + M} = \frac{Mr}{M + m} \quad ...(i)$$

and

$$r_2 = r - r_1 = r - \frac{Mr}{M + m} = \frac{mr}{M + m} \quad ...(ii)$$



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We can suppose that both the planet P and the Sun move about their common centre of mass C. The necessary centripetal force is due to their mutual gravitational attraction. Let v_1 and v_2 be the speed of the planet and the sun about centre of mass C. The radius of the circular orbit of the planet and the sun is r_1 and r_2 respectively. Therefore,

$$\frac{m v_1^2}{r_1} = \frac{GM m}{r^2} \quad ...(iii)$$

$$\frac{m v_2^2}{r_2} = \frac{G M m}{r^2} \quad ...(iv)$$

Let T be the time-period of the planet and the sun about the centre of mass.

Obviously

$$\frac{2\pi r_1}{v_1} = T \text{ and } \frac{2\pi r_2}{v_2} = T \quad ...(v)$$

Substituting value of v_1 and v_2 in terms of T from eqn (v) in eqn (iii) and (iv) we get

$$\frac{m}{r_1}\left(\frac{2\pi r_1}{T}\right)^2 = \frac{G M m}{r^2} \text{ or } \frac{4\pi^2}{T^2} r_1 = \frac{G M}{r^2} \quad ...(vi)$$

and

$$\frac{4\pi^2}{T^2} r_2 = \frac{Gm}{r^2} \quad ...(vii)$$

Using eqn (i) and (vi) or eqn (ii) and eqn (vii) we obtain

$$\frac{4\pi^2}{T^2}\left(\frac{M r}{M+m}\right) = \frac{G M}{r^2} \text{ or } M + m = \frac{4\pi^2}{G}\left(\frac{r^3}{T^2}\right)$$

or

$$(M+m)\frac{T^2}{r^3} = \frac{4\pi^2}{G} = \text{constant} \quad ...(viii)$$

For two planets of mass m_1 and m_2 at distance R_1 and R_2 from the sun; eqn (viii) gives

$$(M+m_1)\frac{T_1^2}{R_1^3} = (M+m_2)\frac{T_2^2}{R_2^3}$$

or

$$\frac{(M+m_1)T_1^2}{(M+m_2)T_2^2} = \frac{R_1^3}{R_2^3} \quad ...(ix)$$

If mass of the sun is very large as compared to the mass of the planet, eqn (ix) reduces to

$$\frac{T_1^2}{T_2^2} = \frac{R_1^3}{R_2^3} \quad [\because M + m_1 \sim M \text{ and } M + m_2 \sim M]$$

$$\therefore \left(\frac{R_1}{R_2}\right)^3 = \left(\frac{T_1}{T_2}\right)^2 \quad ...(x)$$

Knowing T_1 and T_2 the ratio R_1/R_2 is easily obtained from eqn (x).

Q.66. *Write down the expression for the mass of the sun in terms of the orbital radius R and period of revolution, T of a planet around the sun.* **(CBSE 1993 Comptt.) (1)**

Ans. Let the mass of the planet and the sun be denoted by m and M respectively. If v is the speed with which the planet revolves around the sun, we have

$$\frac{mv^2}{R} = \frac{GM m}{R^2} \Rightarrow v^2 = \frac{GM}{R}$$

Now $v = 2\pi R/T$, where T is the period of revolution of the planet around the sun.

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$$\frac{4\pi^2R^2}{T^2} = \frac{GM}{R}$$

or
$$M = \frac{4\pi^2R^3}{GT^2}$$

This gives the mass of the sun in terms of the orbital radius R and the period of revolution T, of planet around the sun.

Q.67. *How is the luminosity of a star affected by increase in its mass?* **(CBSE 1995) (1)**

Ans. As the mass of a star increases, its luminosity increases roughly as the $\left(3\frac{1}{2}\right)$th power of the mass.

Thus, luminosity $\propto$ (mass)$^{7/2}$

Q.68. *Define the term absolute magnitude of a star.* **(CBSE 1994) (1)**

Ans. The absolute magnitude of a star is indicative of its true or intrinsic brightness. We say that the absolute magnitude of a star corresponds to the brightness of the star if it were taken to some standard distance. (The standard distance usually chosen is 32.6 light years from the sun from its actual position).

Q.69. *What is meant by the "absolute brightness" of a star?* **(1)**

Ans. The absolute brightness of a star is its brightness if it were at some standard distance from the observer.

Q.70. *What is the ratio of brightness of two stars whose magnitude differ by unity?* **(1)**

Ans. The ratio of the brightness of two stars of magnitudes n and (n + 1) is 2.512 : 1.

Q.71. *Two stars differ in brightness by a factor of 100. What is the difference in their magnitudes?* **(1)**

Ans. We have $100 \approx (2.512)^5$

It follows that $\frac{\text{Brightness of a star of magnitude n}}{\text{Brightness of a star of magnitude (n + 5)}} = (2.512)^5 = 100$

Thus, the difference in the magnitudes of two stars, whose brightness differs by a factor of 100, is *five*. The brighter of the two stars will have a lower magnitude associated with it.

Q.72. *There are certain stars, called 'variable stars' which undergo perodic changes in their light output. If such a star doubles its light output, how much does its magnitude change?* **(CBSE 1993 Comptt.) (2)**

Ans. When the light output of a star gets doubled, let its magnitude change from m_1 to m_2. We then have

$$m_2 - m_1 = -2.5 \log\left(\frac{I_2}{I_1}\right)$$

Given $I_2 = 2I_1$. Therefore, $\Delta m = m_2 - m_1 = -2.5 \log (2) = -2.5 \times 0.3 = -\mathbf{0.75}$.

The magnitude of the star decreases by **0.75.**

Q.73. *How is the "brightness magnitude scale" of stars defined? Show that the ratio of brightness of two star of magnitudes n_1 and n_2 is $(100)^{(n_2 - n_1)/5}$.* **(3)**

Ans. The brightness magnitude scale is defined as follows :

$$\frac{\text{Brightness of a star of magnitude n}}{\text{Brightness of a star of magnitude n + 1}} = \frac{2.512}{1}$$

Thus, a star of magnitude 2 is 2.512 less bright than a star of magnitude 1.

We have $\frac{\text{Brightness of a star of magnitude } n_1}{\text{Brightness of a star of magnitude 0}} = \frac{1}{(2.512)^{n_1}}$

Similarly $\frac{\text{Brightness of a star of magnitude } n_2}{\text{Brightness of a star of magnitude 0}} = \frac{1}{(2.512)^{n_2}}$

$$\therefore \frac{\text{Brightness of a star of magnitude } n_1}{\text{Brightness of a star of magnitude } n_2} = (2.512)^{(n_2 - n_1)}$$

But, $(2.512) = (100)^{1/5}$

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$$\therefore \quad \frac{\text{Brightness of a star of magnitude } n_1}{\text{Brightness of a star of magnitude } n_2} = (100)^{\frac{(n_2 - n_1)}{5}}$$

Q.74. *Prove that the stars with a negative magnitude are brighter than those with a positive magnitude.* (2)

Ans. We have $\frac{\text{Brightness of a star of magnitude } (-n)}{\text{Brightness of a star of magnitude } 0} = \frac{1}{(2.512)^{-n}} = (2.512)^n$

Similarly, $\frac{\text{Brightness of a star of magnitude } (+n)}{\text{Brightness of a star of magnitude } 0} = \frac{1}{(2.512)^n}$

$$\therefore \quad \frac{\text{Brightness of a star of magnitude } (-n)}{\text{Brightness of a star of magnitude } (+n)} = (2.512)^n \times (2.512)^n = (2.512)^{2n}$$

It follows that star of magnitude – n is $(2.512)^{2n}$ times as bright as a star of magnitude (+n). Thus, stars with negative magnitude are brighter than those with a positive magnitude.

Q.75. *Does the negative magnitude of a star mean more brightness or less brightness?*

(CBSE 1995 Comptt.) (1)

Ans. A negative magnitude (as explained above in answer no. 74) implies a greater brightness.

Q.76. *State Hubble's law.*

Ans. According to Hubble's law, (1)

The speed of recession of a galaxy is directly proportional to the distance of the galaxy. Thus,

$$v \propto d \quad \text{or} \quad v = Hd$$

The constant of proportionality, H, is known as Hubble's constant.

Q.77. *What is the value of Hubble's constant ?*

Ans. It has been estimated that the value of Hubble's constant is nearly (1)

$$H \approx \frac{50 \text{ km/sec}}{(\text{mega parsec})}$$

Here 1 megaparsec = 10^6 parsec $\approx 3.03 \times 10^6$ light years

$$\approx \mathbf{30 \times 10^{21}\ m.}$$

Q.78. *State Hubble's law. How can this law be used to explain that the universe is expanding?*

(CBSE 1995 Comptt.) (3)

Ans. For statement of Hubble's law, refer to answer no. 77.

According to Hubble's law, the more distant a galaxy is, the faster it is receding away from us. This implies that the more distant galaxies are progressively becoming still more distant from us. This clearly implies an ever expanding universe.

Q.79. *What are dwarf stars?*

Ans. Dwarf stars are stars in the formation stage. The interior temperature of this stars is so high as to bring about nuclear fusion. Huge amount of energy is released by these stars. (1)

Q.80. *What are giant or supergiant stars?*

Ans. These are stars in which all the hydrogen in the interior has been exhausted. The nuclear fusion inside the star has stopped. The radius of these star has become quite large. (1)

Q.81. *What are novas or supernovas?*

Ans. Novas or supernovas are stars in which nuclear fusion takes place at a very fast rate. The energy produced in the star is so high that they are on the brink of explosion. (1)

Q.82. *What are dark stars?*

Ans. The left over and cooled remnants of a supernova explosion of a star are known as dark stars. The name indicates that these stars do not emit any radiations, for all practical purposes. (1)

Q.83. *What are neutron stars?*

Ans. Neutron stars are stars of extremely high densities. Their mass is of the order of 2 solar mass and 3 solar mass. Very intense magnetic fields are associated with neutron stars. The radius is about 10 km only! Neutron stars are formed after the supernova explosion of a star of original mass 2 – (1)

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Q.84. *What are pulsars?* **(1)**

Ans. Pulsars are neutron stars emitting pulses at regular interval. Pulsar is abbreviation for pulsating stars. The period of pulses varies from 30 milli second to about 3 second.

Q.85. *What are quasars?* **(1)**

Ans. Quasar is an abbreviation for quasi-stellar, i.e., star resembling objects. Quasars are star like objects emitting radio frequencies pulses at regular intervals. Quasars are not a part of our galaxy. They are the most distant objects in our universe.

Q.86. *What are black holes?* **(2)**

Ans. Black-holes are objects in the universe having extremely high gravitational pull. They even do not permit a photon to pass by it. The photon is pulled towards the black-hole due to the large gravitational force on it, due to the black-hole. Neither matter nor radiations can escape from inside a black-hole. It also attracts anything passing nearby towards itsef.

Q.87. *Express the Chandrasekhar mass limit in terms of the mass of the sun.* **(1)**

Ans. The 'Chandrasekhar mass limit equals 1.4 times the mass of the sun.

Q.88. *What stars are the "red ones"? What is their "label" and their surface temperature?* **(2)**

Ans. The relatively cool stars are the red stars. They have been labelled as the **M** stars and their surface temperature is less than about 3500 K.

Q.89. *Discuss the use of Wein's displacement law in estimating the surface temperature of a star.* **(2)**

Ans. We know that the wavelength of maximum emission in the spectrum of a black body is inversely proportional to its kelvin temperature. Thus,

$$\lambda_m \propto \frac{1}{T} \text{ or } \lambda_m T = \text{constant} = b, \text{ say}$$

The result is the well known *Wein's displacement law* and the value of the constant b has been determined to be 2.897×10^{-3} m-K. It follows that if we can determine the wavelength of maximum emission in the spectrum of a given star, we can estimate its (black body) surface temperature.

Q.90. *Define 'Solar constant'. Name any two use of this parameter.* **(CBSE 1995 Comptt.) (2)**

Ans. The solar constant equals to total radiant energy, received per unit area per second on the earth, when the area is held normal to the direction of Sun's rays. Its value is nearly 1.388×10^3 W/m^2

We may use the knowledge of solar constant to estimate (i) the surface temperature of the sun, using Stefan's law and (ii) the total amount of Sun's energy received by the earth in a given time interval.

Q.91. *What is meant by the proton-proton cycle?* **(2)**

Ans. We now believe that the source of solar energy is the fusion of four hydrogen nuclei into a single nucleus of helium. The proton-proton cycle is believed to be one of the two ways in which this transformation can come about. The sequence of reactions, in this cycle, is believed to be

$${}_1^1H + {}_1^1H \rightarrow {}_1^2H + {}_1^0e + \nu$$

$${}_1^2H + {}_1^1H \rightarrow {}_2^3He + \nu$$

$${}_2^3He + {}_2^3He \rightarrow {}_2^4He + 2\,{}_1^1He$$

The net result is the reaction

$$4\,{}_1^1H \rightarrow {}_2^4He + 2\,{}_{+1}^0e + 24.7 \text{ MeV}$$

Here ${}_{+1}^0e$ stands for the positron, the antiparticle of the electron.

Q.92. *Give the net result of the carbon-cycle vis-a-vis the fusion process in stars.* **(2)**

Ans. The carbon-carbon cycle is believed to be the second way in which the fusion of four hydrogen nuclei, into a single helium nucleus, can come about. The sequence of 'reactions', in this cycle, is believed to be as follows :

$${}_1^1H + {}_6^{12}C \rightarrow {}_7^{13}N$$

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$$^{13}_{7}N \rightarrow {}^{13}_{6}C + {}^{0}_{+1}e + \nu$$

$$^{1}_{1}H + {}^{13}_{6}C \rightarrow {}^{14}_{7}N + \nu$$

$$^{1}_{1}H + {}^{14}_{7}N \rightarrow {}^{15}_{8}O + \nu$$

$$^{15}_{8}O \rightarrow {}^{15}_{7}N + {}^{0}_{+1}e + \nu$$

$$^{1}_{1}H + {}^{15}_{7}N \rightarrow {}^{4}_{2}He + {}^{12}_{6}C$$

The net result is again the reaction :

$4\ {}^{1}_{1}H \rightarrow {}^{4}_{2}He + 2\ {}^{0}_{+1}e + 24.7$ MeV, the same as in the proton-proton cycle.

Q.93. *What do you know about the classification of stars in terms of their spectra?* (2)

Ans. One of the very useful and precise techniques available to the modern astronomer is the study of the spectra from various heavenly objects. When the spectra of stars were studies, it was found that they were not quite the same. Stars were, therefore, classified in terms of their spectra as O, B, A, F, G, K and M stars. The following table gives the details relevant to these different types of stars.

Type and colour of the Star	Approximate Temperature (K)	Mass (in solar mass units)	Radius (in units of solar radius)	Luminosity (as compared with sun's luminosity)
O, Blue	> 25000	~ 4.0	~ 0	10^3
B, Blue	11000—25000	~ 1.5	~ 7	10^4
A, White	7500—11000	~ 2.3	~ 1.8	$\sim 2.5 \times 10$
F, Green	6000—7500	~ 1.4	~ 1.2	$\sim 0.3 \times 10$
G, Yellow	5000—6000	~ 1.0	~ 1.0	1
K, Orange	3500—5000	~ 0.7	~ 0.8	$\sim 4 \times 10^{-1}$
M, Red	< 3500	~ 0.3	~ 0.4	$\sim 2.5 \times 10^{-3}$

Q.94. *Derive the expression connecting the mass of a binary star system with its period of revolution.* **(CBSE 1994)** (3)

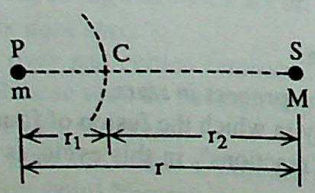
Ans. Consider a binary star consisting of two stars of masses m and M separated by a distance r. The two stars can be regarded as revolving about the centre of mass of the system whose distances from the two stars, say, r_1 and r_2 are given by

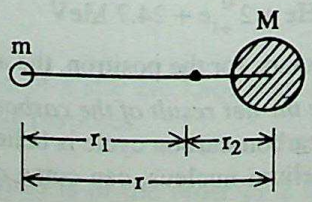
$$r_1 = \frac{M}{m+M} r \quad \text{and} \quad r_2 = \frac{m}{m+M} r$$

The two stars can be regarded as revolving about the common centre of mass with a common angular velocity ω such that

$$M\omega^2 r = \frac{G M (M+m)}{r^2} \quad \text{and} \quad m\omega^2 r = \frac{G m (M+m)}{r^2}$$

From either of these equations, we get





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$$\omega^2 r^3 = G(M + m)$$

$$\text{or } (M + m) = \frac{1}{G}\omega^2 r^3 = \frac{1}{G} \cdot \frac{4\pi^2}{T^2} r^3$$

The mass (M + m) of the binary star system in, thus, related to T, the (common) period of revolution (of the two stars about the centre of mass) by the relation.

$$(M + m) = \frac{4\pi^2}{G} \cdot \frac{r^3}{T^2}$$

Q.95. *Derive the expression connecting the mass of binary star system with its-period of revolution.*

(CBSE 1993) (3)

Ans. Refer to Answer no. 94 above.

Q.96. *Give a method for determining the size of a star.* **(CBSE 1993) (3)**

Ans. Refer to Answer no. 65.

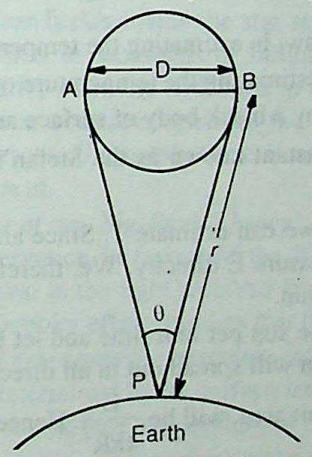
Q.97. *What is meant by the "black body temperature" of a star?*

Ans. The temperature of a star is estimated by using either Wien's displacement law or the Stefan's law. Both these laws are strictly valid for a black body only. The temperature of a star, estimated on the basis of either of these laws, is, therefore, often referred to as the black body temperature of the star. It implies that a black body, at this estimated temperature, would be radiating the same amount of energy, per unit area per unit time, as the star, under consideration, is radiating.

Q.98. *With the help of a diagram, describe the method for determining the diameter of a planet.*

(CBSE 1997 Comptt.) (2)

Ans. When a heavenly body (like moon) is seen through a telescope, it appears as a disc. Using telescope, we measure the angle θ, subtended by the diameter of the planet at a point on the surface of the earth.



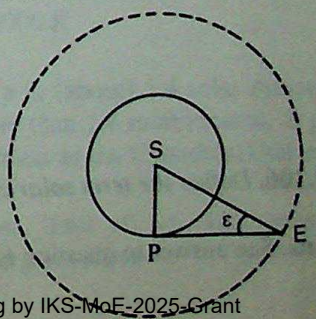
If r be the distance of the planet from earth, and D be the diameter of the planet, then $\theta = \frac{D}{r} \Rightarrow D = r\theta$.

Q.99. *Describe how the distance of an inferior planet from the sun can be determind.*

(CBSE 1997 Comptt., 1999, 2000) (2)

Ans. Distance of an inferior planet (such as Venus) from the sun can be determined on the basis of measurement of their angle of maximum elongation.

In the figure, planet P and earth E are on their orbits around the sun S. When the planet P is in the maximum elongation, then $\angle SPE = 90^\circ$ and ϵ is maximum.



Now, $\sin \epsilon = \frac{SP}{SE}$ or $SP = SE \sin \epsilon$

SE is the distance of sun from the earth which is equal to (1) A.U.

$SP = A.U. \sin \epsilon$.

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Q.100. *Explain, how the surface temperature of a planet is measured.* **(CBSE 1997) (3)**

Ans. Every planet radiates energy in the form of thermal radiation. By knowing the amount of thermal energy (E) emitted per second per unit area of the planet, its surface temperature (T) can be determined by using Stefan's law.

$E = \sigma T^4$, where σ is Stefan's constant.

Q.101. *The wavelength of light coming from a distant galaxy is red shifted. Is the galaxy receding or approaching the earth?* **(CBSE 2000) (1)**

Ans. The galaxy is receding the earth.

Q.102. *Briefly explain how the distance of an inferior planet from earth can be determined.* **(CBSE 2000) (2)**

Ans. See answer to question no. 99.

Q.103. *How does luminosity of stars vary with their radii?* **(CBSE 2000) (1)**

Ans. Luminosity $\propto$ (radius)^2.

Q.104. *Briefly, explain how the distance of a superior planet from earth can be found using Kepler's third law.*

Ans. The distance of a superior planet can be determined with the help of Kepler's third law.

$T^2 \propto R^3$, where T is period of revolution and R is the semi-major axis of the planet's orbit.

For two planets, we can write $\frac{T_1^{\,2}}{T_2^{\,2}} = \frac{R_1^{\,3}}{R_2^{\,3}} \Rightarrow R_2 = R_1 \left(\frac{T_2}{T_1}\right)^{2/3}$

Knowing R_1, T_1, T_2, the value of R_2 can be calculated.

Q.105. *How do we use the Wein's displacement law and the Stefan's law in estimating the surface temperature of a star?*

Ans. For use of Wien's displacement law, in estimating the temperature of a star, refer to answer no. 89.

We may also use Stefan's law also for estimating the temperature of stars. According to this law,

The total energy emitted per unit time by a black body of surface area A at a temperature T (kelvin) is given by $E = \sigma AT^4$, where σ is a (universal) constant known as the Stefan's constant. Its accepted value is (nearly) 5.669×10^{-8} Wm^{-2} K^{-4}.

It follows that if we can determine E, we can estimate T. Since an star would be radiating its energy in all directions in space, it is not possible to measure E directly. We, therefore, follow an alternative method which we illustrate by considering the case of the sun.

Let E be the total energy radiated by the sun per unit time and let R be the radius of the Earth's orbit round the sun. Since the energy radiated by the sun will spread out in all directions, the amount of this energy received per second at the surface of the earth, per unit area, will be $\frac{E}{4\pi R^2}$. Hence, the solar constant S is given by

$$S = \frac{E}{4\pi R^2} \text{ watt } m^{-2}$$

The *solar constant* can clearly be measured on the Earth. Its experimental value is nearly 1.388×10^3 Wm^{-2}.

From a knowledge of S, we can get E and, from a knowledge of E, we can get T, the temp. of the sun. We have

$$E = 4\pi R^2 S = \sigma AT^4 = \sigma (4\pi r^2) T^4$$

$$\therefore \quad T = \left[\left(\frac{R}{r}\right)^2 . \frac{S}{\sigma}\right]^{1/4}$$

Q.106. *Define the term solar constant. How can the surface temperature of the sun be determined?*

Ans. See answer to question no. 105. **(CBSE 1994, Comptt.) (3)**

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Q.107. *How does one estimate the temperature of the sun?* **(CBSE 1995) (3)**

Ans. See answer to question no. 105.

Q.108. *Derive the mathematical expression for the surface temperture of the sun in terms of solar constant.* **(CBSE 1998, 1999) (2)**

Ans. See answer to question no. 105.

Q.109. *Define the terms solar constants and solar luminosity. Explain, how their knowledge help us to calculate the surface temperature of the sun. Derive necessary mathematical expressions.* **(CBSE 1998) (3)**

Ans. See answer to question no. 105.

Q.110. *What is the mechanism of energy production in stars? Explain the sequence of steps and the final result in the two "cycles" believed to be responsible for this energy production.* **(3)**

Ans. The energy produced in stars is believed to be due to nuclear reactions. Bethe proposed that in the interior of stars temperature is so high that matter exists in an ionised state known as *plasma* and nuclear fusion takes place producing enormous amount of energy. The source of solar energy is believed to be conversion of four hydrogen nuclei into helium. There are two possible ways in which this can happen. These are the proton-proton cycle and the carbon-carbon cycle. For details of these, refer to answer to question no. 91 and 92.

The energy yield of both the cases works out to be 24.7 MeV per 4 hydrogen atoms.

A star is, thus, continuously 'consuming' its hydrogen to release energy. The 'life' of a star, thus, depends on its 'total hydrogen content' and its rate of consumption of this 'fuel'.

Q.111. *Give a brief account on the "evolution" and different stages in the life of a star.* **(3)**

Ans. The evolution of a star involves (i) the birth, (ii) the life and (iii) the death of the star. We believe that when inter-stellar dust and gases in a region acquire a mass more than thousand times that of the sun, they start exerting huge gravitational force of attraction on one another. The interstellar matter contracts resulting in the release of gravitational potential energy. The energy released is sufficient to raise the temperature in the interior to a few ten million degree or more. Nuclear fusion inside the star starts taking place and the star is born. The star continues to live for hundreds of million to thousands of billion years. All this time the nuclear fusion, inside, the star keeps on taking place. Finally, when the hydrogen in the interior of the star gets exhausted, the star starts cooling. The inner core of the star contracts, whereas the outer layers expand. The size of the star increases and its surface temperature decreases. Ultimately there is an explosion which throws out most of the stellar matter in space. The original star is dead.

Q.112. *Name one observation in favour of the 'Big-Bang Theory'* **(CBSE 1995) (1)**

Ans. One of the most significant observation in favour of the Big-Bang theory is so called *Doppler Red shift*. It has been found that the spectral lines, in the light received from a star, show a shift towards the longer wavelength (a red shift). This, in terms of Doppler effect, implies that the stars are receding away from us.

Q.113. *Name the parameter which will determine the apparent colour of a star.* **(CBSE 1995) (1)**

Ans. The apparent colour of a star is determined by its surface temperature take on answer no 93 gives the corelation between the apparent colour and the surface temperature of the star.

Q.114. *Write the sequence of stellar spectra which arranges the stars in order of decreasing temperature. To which stellar class does our sun belong?* **(CBSE 1994) (2)**

Ans. The sequence of stellar spectra arranging the stars, in order of decreasing temperature, is O, B, A, F, G, K and M. (The colours associated with these categories are Blue, Blue, White, Green, Yellow, Orange and Red respectively).

Our sun is a 'G' type stellar spectra class star with a temperature of nearly 6000 K.

Q.115. *What is the significance of the Chandrasekhar mass limit?* **(2)**

Ans. When the mass of a star is of the order of the mass of the sun, or up to (about) 1.4 solar masses, it grows over to form what is known as a white dwarf. However, if its mass is more than 1.4 solar masses, it goes to 'form') a neutron star. We call this transition mass value of about 1.4 solar mass as the Chandrasekhar mass limit.

We, thus, see that the mass of a star, vis-a-vis the Chandrasekhar mass, limit of, i.e., solar masses, determines whether it is going to form a white dwarf or a neutron star from its red giant phase.

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SOLVED NUMERICAL PROBLEMS ON UNIT – XIII

Example 1. *(i) Surface temperatures of two stars are in the ratio 1:2. What is the ratio of energy radiated by them per sec.?* **(CBSE 1998 Comptt.)**

(ii) Two stars A and B have brightness ratio – 2 and + 4 respectively. Which star appear brighter? **(CBSE 1999)**

(iii) The value of solar constants of two planets A and B are in the ratio of 1 : 16. Which planet has larger surface temperature? **(CBSE 1999)**

(iv) What is the ratio of solar constants on the surface of two planets, whose surface temperatures are in the ratio of 1 : 2? **(CBSE 2000)**

Solution: (i) We know that $E \propto T^4$

$\Rightarrow E_1 : E_2 = T_1^4 : T_2^4 = 1 : 2^4 = 1 : 16$

(ii) Star A appears brighter

(iii) $\frac{S_1}{S_2} = \frac{T_1^{\,4}}{T_2^{\,4}} = \frac{1}{16} \Rightarrow \frac{T_1}{T_2} = \frac{1}{2}$

$\Rightarrow$ B has more surface temperature.

(iv) $\frac{S_1}{S_2} = \frac{T_1^{\,4}}{T_2^{\,4}} = \left(\frac{1}{2}\right)^4 = \frac{1}{16}$

$\Rightarrow S_1 : S_2 = \mathbf{1 : 16.}$

Example 2. *A satellite of Jupiter moves in an orbit of radius 4.22×10^5 km. Its period is 1.77 days. What is mass of Jupiter? Given $G = 6.67 \times 10^{-11}$ M.K.S. unit.*

Solution : Let M and m denote mass of Jupiter and its satellite and r the radius of orbit. If v is speed of satellite and T its time-period.

$$G\frac{Mm}{r^2} = \frac{mv^2}{r} \text{ or } v^2 = \frac{GM}{r}. \quad \text{and} \quad T = \frac{2\pi r}{v}$$

Therefore, $$\frac{4\pi^2 r^2}{T^2} = \frac{GM}{r} \text{ or } M = \frac{4\pi^2}{G}\left(\frac{r^3}{T^2}\right).$$

Given $G = 6.67 \times 10^{-11}$ M.K.S. unit, $r = 4.22 \times 10^5$ km $= 4.22 \times 10^8$ m and

$T = 1.77$ day $= 1.77 \times 24 \times 3600$ s

$$\therefore \quad M = \frac{4 \times (3.142)^2 \times (4.22 \times 10^8)^3}{6.67 \times 10^{-11} \times (1.77 \times 24 \times 3600)^2} \text{ kg} \approx \mathbf{1.9 \times 10^{28}\ kg.}$$

Example 3. *Solar constant at the surface of earth is 1.4 kW/m^2. Compute solar constant for Jupiter. Distance of Jupiter from the sun is 5.2 A.U.*

Solution : The energy reaching a planet from the sun is inversely proportional to the square of its distance from the sun and solar constant is energy received per unit area per unit time. Let S_1 and r_1 be the solar constant and the radius of earth's orbit around the sun. The corresponding quantities for Jupiter are S_2 and r_2. Then

$$\frac{S_1}{S_2} = \left(\frac{r_2}{r_1}\right)^2$$

Given $S_1 = 1.4$ kW/m^2 $= 1400$ W/m^2; $r_2 = 5.2\, r_1$

$$\therefore \frac{1400}{S_2} = (5.2)^2 \text{ or } S_2 = \frac{1400}{(5.2)^2} = \mathbf{51.76\ Wm^{-2}}.$$

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Example 4. *Distance of the planet Venus from the sun is 0.72 A.U. Find the orbital period of Venus.* **(CBSE 1993 Comptt)**

Solution : We know that, as per Kepler's third law $T^2 \propto a^3$

$$\therefore \left(\frac{T_1}{T_2}\right)^2 = \left(\frac{a_1}{a_2}\right)^3$$

Here T_1 and a_1 refer to the time period and orbital radius of Venus while T_2 and a_2 are the corresponding quantities for earth.

Now $T_2 = 1$ year and $a_2 = 1$ A.U.

Hence,

$$\left(\frac{T_1}{1}\right)^2 = \left(\frac{0.72}{1}\right)^3$$

$\therefore \quad T_1 = (0.72)^{3/2}$ years $= 0.611$ earth year $\approx 0.611 \times 365$ earth days $=$ **223 earth days.**

Example 5. *Period of revolution of moon around earth is 27.32 days. The mean distance of the moon from earth is* 3.844×10^5 *km. What is the sum of the mass of the earth and the moon?* $G = 6.67 \times 10^{-11}$ *M.K.S. unit.*

Solution : Let M and m denote the mass of the earth and the sun respectively. If T is period of moon around earth in an orbit of radius r

$$M + m = \frac{4\pi^2}{G}\frac{r^3}{T^2}$$

Given $\quad r = 3.844 \times 10^5$ km $= 3.844 \times 10^8$ m; $T = 27.32$ day

$= 27.32 \times 24 \times 3600$ s, $G = 6.67 \times 10^{-11}$ M.K.S. Unit

$$\therefore \quad M + m = \frac{4 \times (3.142)^2 \times (3.844 \times 10^8)^3}{6.67 \times 10^{-11} \times (27.32 \times 24 \times 3600)^2} \text{ kg} \approx \mathbf{6.04 \times 10^{24}\ kg.}$$

Example 6. *Define absolute magnitude of a star. Assuming that the dimmest star visible to the naked eye has magnitude of 6. Compare its brightness with that of planet Venus which has a magnitude – 4.* **(CBSE 1998)**

Solution: See theoretical section for 1st part.

Magnitude of Venus, $m_2 = -4$

Let l_1 and l_2 be the brightness of the dimmest star and Venus respectively

Then $\frac{l_1}{l_2} = 100^{\left(\frac{m_2 - m_1}{5}\right)} = 100^{\left(\frac{-4-6}{5}\right)} = \frac{1}{(100)^2} = \frac{1}{10000}$.

Hence, the dimmest star visible to the naked eye is 10000 times fainter than Venus.

Example 7. *How much total energy will be produced if the total mass of the sun is converted into energy? How long will this enable the sun to continue to radiate at its present rate? Given*

mass of the sun $= 2 \times 10^{30}$ *kg; speed of light* $= 3 \times 10^8$ ms^{-1}

present rate of energy radiated by the sun $= 1.2 \times 10^{34}$ *J/year.*

Solution : According to Einstein's mass-energy relation, the energy produced $E = mc^2$, where m is mass converted into energy and c is speed of light.

$\therefore \quad E = 2 \times 10^{30} \times (3 \times 10^8)^2$ J $= \mathbf{1.8 \times 10^{47}\ J}$

Let T be the time for which sun will continuing radiating at present. Then,

$$T = \frac{1.8 \times 10^{47}}{1.2 \times 10^{34}} \text{ year} = \mathbf{1.5 \times 10^{13}\ year.}$$

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Example 8. *In 1975, a nova appeared in the constellation of cygnus. In two days the magnitude of the star changed for + 15 to + 2. By what factor did its brightness increase?*

Solution : If l_1 and l_2 denote the brightness of star when its magnitude is m_1 and m_2 respectively. Then,

$$m_2 - m_1 = -2.5 \log (l_2/l_1)$$

Given $m_2 = +2,\ m_1 = +15$

$$\therefore \quad 13 = 2.5 \log \left(\frac{l_1}{l_2}\right) \text{ or } \log \left(\frac{l_1}{l_2}\right) = \frac{13}{2.5} = 5.2$$

$$\therefore \quad \frac{l_1}{l_2} = \text{antilog } 5.2 = \mathbf{1.6 \times 10^5}$$

The brightness of the star decreased nearly by a factor of **0.16 million.**

Example 9. *There are certain stars called ' variable stars' which undergo periodic changes in their light output. If one such star doubles its light output, how much does its magnitude change?*

(CBSE 1993 Comptt.)

Solution : If I_1 and I_2 are the initial and final light outputs, we have $\frac{I_1}{I_2} = \frac{1}{2}$

Let m_1 and m_2 be the corresponding magnitudes. We then have,

$$m_2 - m_1 = -2.5 \log \left(\frac{I_2}{I_1}\right) = -2.5 \log (2) = -2.5 \times 0.3010 \approx -0.75$$

Thus the new magnitude is **0.75** less than the original magnitude.

Example 10. *Dependent on its temperature, each star has its own characteristic wavelength of maximum emission. If this wavelength for a star lies in the range 6200 Å, to 7700 Å, the star appears red; similarly for this wavelength in the range 4600 Å to 4900 Å the star appears blue. Assuming the validity of Wien's law* ($\lambda_m T = b = 2.897 \times 10^{-3}$ *mK), calculate the range of temperatures for (i) a red star, (ii) a blue star.*

Solution : (i) For a red star, the minimum temperature in kelvin is $T_{min} = \frac{2.897 \times 10^{-3}}{7700 \times 10^{-10}}$ K = 3762 K

Similarly, the maximum temperature is $T_{max} = \frac{2.897 \times 10^{-3}}{6200 \times 10^{10}}$ K = 4672 K

Thus, the temperature range for a red star is **3762 K to 4672 K.**

(ii) For a *blue* star, the minimum temperature in kelvin is $T_{min} = \frac{2.897 \times 10^{-3}}{4900 \times 10^{-10}}$ K = 5912 K

and the maximum temperature is $T_{max} = \frac{2.897 \times 10^{-3}}{4600 \times 10^{-10}}$ K = 6493 K

Thus, the temperature range for a *blue* star is **5912 K to 6493 K.**

Example 11. *A galaxy is receding from earth at a speed of* 6×10^3 *kms*$^{-1}$. *Estimate the distance of the galaxy in light year and parsec. Given, Hubble's constant = 17 kms*$^{-1}$ *per million light year.*

Solution : From Hubble's law $d = v/H$

where d and v denote the distance and speed of the galaxy and H is Hubble's constant. Given, H = 17 kms^{-1} per million light year, $v = 6 \times 10^3$ kms^{-1}

$$\therefore \quad d = \frac{6 \times 10^3}{17} \times 10^6 \text{ light year} \approx \mathbf{3.53 \times 10^8 \text{ light year.}}$$

We know that 1 parsec = 3.3 light years

$$\therefore \quad d = \frac{3.53 \times 10^8}{3.3} \text{ parsec} \approx \mathbf{1.07 \times 10^8 \text{ parsec.}}$$

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C.B.S.E. Sample Paper I 1996

Time allowed : 3 Hours **Maximum Marks 70**

General Instructions :

(i) All questions are compulsory.

(ii) Marks for each question are indicated against it.

(iii) Question numbers 1 to 8 are very short answer questions, carrying 1 mark each. They are to be answered in one or two sentences.

(iv) Question numbers 9 to 18 are short answer questions, each carrying 2 marks. Answer to these questions should be around 30 words each.

(v) Question numbers 19 to 27 are also short answer questions, each carrying 3 marks. Answer to these questions should be around 50 words each.

(vi) Question numbers 28 to 30 are long answer questions, each carrying 5 marks. Answer to them should be around 150 words each.

(vii) Use log tables, if necessary.

Q. 1 What is the role of MnO_2 in a dry cell? 1

Ans. MnO_2 acts as a depolarizer.

Q. 2 Define one Lumen. 1

Ans. One Lumen is the luminous flux emitted per unit solid angle (steradian) by a uniform point source having luminous intensity of one candela.

Q. 3 A wire of resistivity ρ is stretched to three time its length. What will be its new resistivity? 1

Ans. The resistivity will remain the same, i.e., ρ only.

Q. 4 Why radial magnetic field is used in moving coil galvanometer? 1

Ans. In radial magnetic field, current is directly proportional to the deflection of coil which makes the scale linear and can be easily caliberated.

Q. 5 How is the resolving power of a telescope affected on increasing the aperture of its objective? Give reason for your answer. 1

Ans. The resolving power of telescope is given by

$$\delta\theta = 122\frac{\lambda}{a}.$$

Where λ is wavelength, and a is aperture

For higher resolving power, $\delta\theta$ should be small, and hence a, the aperture should be large.

Q. 6 Suppose there existed a planet that went around the sun twice as fast as the earth. Will its orbital size be more or less than that of the earth? Give reason for your answer. 1.

Ans. Radius of the orbit of planet will be $\frac{1}{4}$ of the radius of the earth's orbit.

$$\frac{V_1}{V_2} = \sqrt{\frac{r_2}{r_1}} \Rightarrow \frac{1}{2} = \sqrt{\frac{r_2}{r_1}} \Rightarrow \frac{1}{4} = \frac{r_2}{r_1}$$

$$\therefore r_2 = \frac{r_1}{4}$$

Q. 7 An electric lamp connected in series with a capacitor and an A.C. source is glowing with certain brightness. How does the brightness of the lamp change on reducing the capacitance? 1

Ans. Total impedance of the circuit is

$$Z = \sqrt{R^2 + X_C^2}$$

where X_C is the reactance of capacitor.

$$X_C = \frac{1}{\omega C}$$

so, as C decreases Z increases, and hence, the brightness will decrease.

Q. 8 A lens of focal length *f* is divided into two equal halves as shown alongside. What is the focal length of each half? 1

Ans. Each half will have a focal length 2*f*.

Q. 9 What is the red shift? What does it indicate? 2

Ans. As a star moves away from the earth, due to

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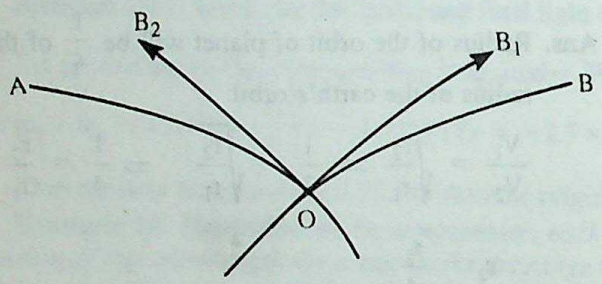
Doppler's effect the apparent frequency is less than the real frequency. This results in an increase in wavelength which is known as the red shift. Red shift indicates the expansion of universe.

Q. 10 What is the name given to the curves, the tangent to which at any point gives the direction of the magnetic field at that point? Can two such curves intersect each other? Justify your answer. 2

Ans. These curves are magnetic lines of force. No, two lines of force can never intersect. Intersection of two lines means two values of magnetic flux density at the same point, which is not possible.



$\vec{B_1} \neq \vec{B_2}$ is not possible at the same point O.

Hence, no two lines of force can intersect.

Q. 11 Write two differences between interference and diffraction patterns of light. 2

Ans. (1) In interference pattern fringes in general are equally spaced, whereas, diffraction pattern has unequally spaced fringes.

(2) In interference all fringes are equally bright, which may not be true in the case of diffraction pattern.

Q. 12 Calculate the refractive index of material of an equilateral prism for which the angle of minimum deviation is 60°. 2

Ans. Here, $\delta m = 60°$ Angle of equilateral prism $A = 60°$

$$\mu = \frac{\sin\frac{A + \delta m}{2}}{\sin A/2} = \frac{\sin\frac{60 + 60}{2}}{\sin 60/2} = \frac{\sin 60}{\sin 30}$$

$$= \frac{\sqrt{3}/2}{1/2} = \sqrt{3}.$$

$$\therefore \mu = \sqrt{3}.$$

Q. 13 You are provided with a compass needle and a dip needle. If you go to the magnetic north pole of the earth and place the two needles there, what would you observe with regard to deflection of the two needles and why? 2

Ans. The compass needle may stop at any random position at the poles. The dip needle will always stand in vertical position. This is so because at poles, the horizontal component of earth's magnetic field is zero only the vertical component exists.

Q. 14 A circular brass loop of radius a and resistance R is placed with its plane perpendicular to a magnetic field which varies with time as $B = B_0 \sin \omega t$. Obtain the expression for the induced current in the loop. 2

Ans. Given, the radius of the brass loop = a

Its area $A = \pi a^2$, $B = B_0 \sin \omega t$

The flux $= \phi = B.A = B_0 \sin \omega t \times \pi a^2$

The induced e.m.f

$$e = \frac{d\phi}{dt} = \frac{d}{dt}(B_0 \sin \omega t)(\pi a^2)$$

$$\therefore e = -B_0 \pi a^2 \omega \cos \omega t$$

$$\text{Also, } e = IR \text{ or } I = \frac{e}{R} = -\frac{B_0 \pi a^2 \omega \cos \omega t}{R}$$

$$\therefore I = -\left(\frac{B_0 \pi a^2 \omega}{R}\right) \cos \omega t.$$

Q.15 How will the following be affected in the absence of atmosphere around the earth? 2

(a) Surface temperature of earth.

(b) Range of radiowaves transmission.

Ans. (a) The surface temperature of the earth will fall due to the absence of "green house effect".

(b) Range of radiowave transmission will decrease due to the absence of ionosphere, which helps in radio communication.

Q. 16 A microscope is focused on a dot at the bottom of a beaker. Some oil is poured into the beaker to depth y cm and it is found necessary to raise the microscope through a vertical distance x cm to bring the dot into focus. Express refractive index of the oil in terms of x and y. 2

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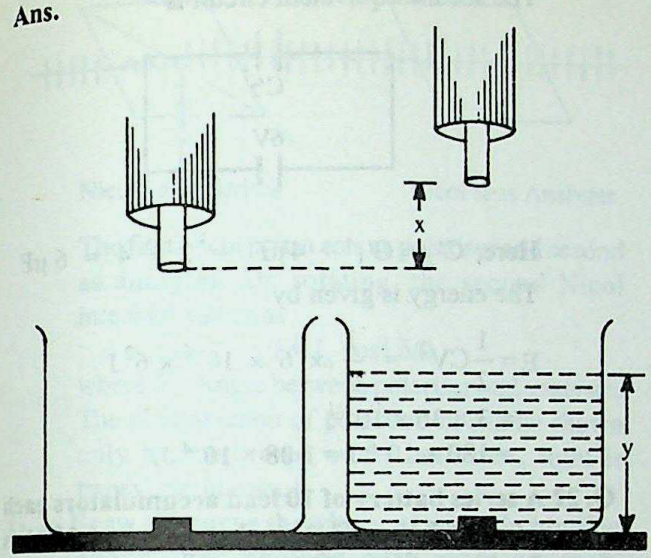
Ans.



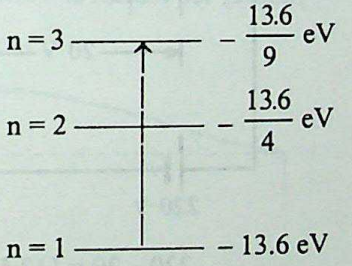
Real depth = y

Apparent depth = y – x

$$\mu = \frac{\text{Real depth}}{\text{Apparent depth}} = \frac{y}{y - x}.$$

Q. 17 The energy of an electron in the nth orbit is given by $E_n = -13.6/n^2$eV. How much energy is required to take an electron from ground state to the second excited state? 2

Ans.



$$E_n = -\frac{13.6}{n^2}\text{ eV}$$

$E_{ground} = -13{\cdot}6$ eV as $n = 1$

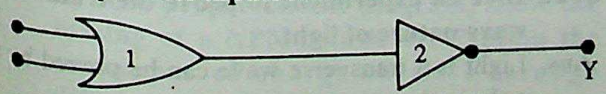
For second excited state, n = 3

The energy is given by the difference in energies of the two states.

$$13.6 - \frac{13.6}{9} = \frac{13.6 \times 8}{9}\text{ eV} = \frac{108.8}{9}\text{ eV}$$

$$= 12.04\text{ eV}.$$

Q. 18 Identify the logic gates 1 and 2 in the logic circuit given below. Also write truth table for all possible inputs A and B. 2

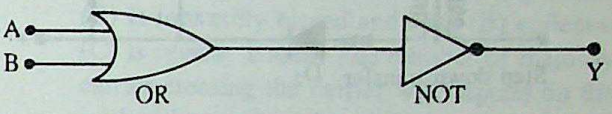


Ans. The gate is NOR gate.

$Y = \overline{A + B}$

TRUTH TABLE

A	B	Y
0	0	1
1	0	0
0	1	0
1	1	0



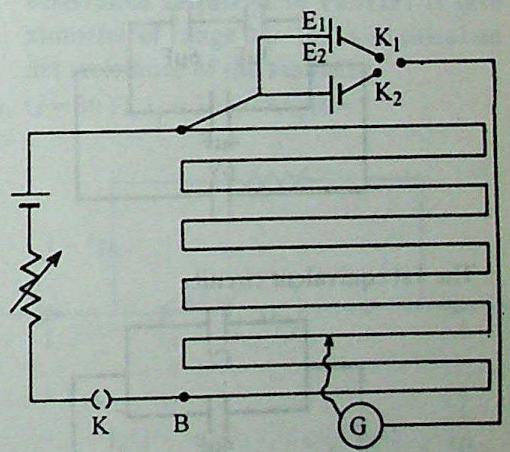
Q. 19 With the help of a circuit diagram explain how would you compare the E.M.F.'s of two primary cells using a potentiometer. 3

Ans. Let k = potential gradient on the wire when the key K is inserted K_1 and K_2 being off. First balance point is obtained by inserting the key K_1 (when K is already on) and let the length on the potentiometer is L_1. The second balance point is obtained by inserting K_2 and K (K_1 is off) at length L_2.

Then $E_1 = kL_1$ and $E_2 = kL_2$

$$\therefore \frac{E_1}{E_2} = \frac{L_1}{L_2}$$

The circuit diagram is as shown.



Q. 20 What is rectification? With the help of a labelled circuit diagram explain full-wave rectification using junction diodes. 3

Ans. The process of changing A.C. to pulsating D.C. by using electronic circuit is called rectification. The full-wave rectification is obtained by using a pair of diodes as shown in the circuit diagram of full-wave rectification.

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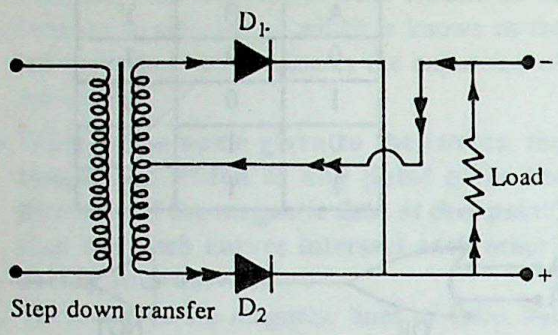
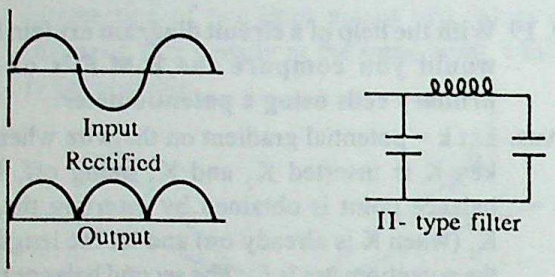
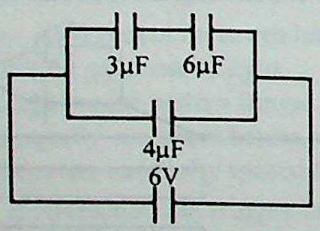


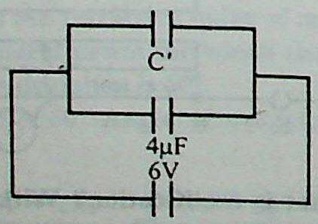


Q. 21 Two capacitors of capacitances $C_1 = 3\mu F$ and $C_1 = 6\mu F$ arranged in series are connected in parallel with a third capacitor $C^3 = 4\mu F$. The arrangement is connected to a 6.0 V battery. Calculate the total energy stored in the capacitors. 3

Ans.



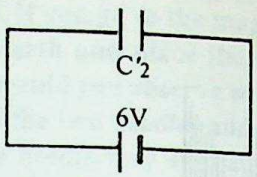
The 1st equivalent circuit



Here, $\frac{1}{C'_1} = \frac{1}{3} + \frac{1}{6}$

$C'_1 = \frac{3 \times 6}{3 + 6} = \frac{18}{9} = 2\mu F$.

The second equivalent circuit is



Here, $C'_2 = C'_1 + 4\mu F = 2 + 4 = 6\ \mu F$

The energy is given by

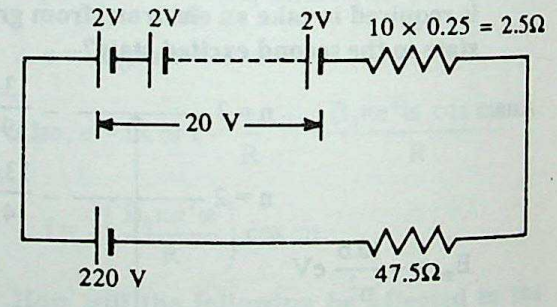
$E = \frac{1}{2}CV^2 = \frac{1}{2} \times 6 \times 10^{-6} \times 6^2 J$

$= 3 \times 36 \times 10^{-6} J$

$= 180 \times 10^{-6}\ J = 1{\cdot}08 \times 10^{-4}$ **J.**

Q. 22 A series battery of 10 lead accumulators each of e.m.f 2 V and internal resistance 0·25 ohm is charged by a 220 V D.C. mains. To limit the charging current a resistance of 47·5 ohm is used in series in the charging circuit. What is (a) the power supplied by the mains and (b) power dissipated as heat? Account for the difference of power in (a) and (b). 3

Ans. Using Kirchhoff's law to the below circuit



$220 - 20 = I\ (2{\cdot}5 + 47{\cdot}5)$

$\therefore\ I = \frac{200}{50} = 4$ A.

Power dissipated $= I^2R = (4)^2 \times 50 = 16 \times 50$
$= 800$ watts

Power used $= 2 \times 10 \times 1 = 20 \times 4 = 80$ watts.

Power supplied by the mains = 880 watts.

Due to the current flowing through the internal and external resistance 800 watts are dissipated and only 80 watts are used for charging.

Q. 23 Give an experiment to prove the transverse wave nature of light. 3

Ans. Light is a transverse wave can be proved by a polarisation experiment :

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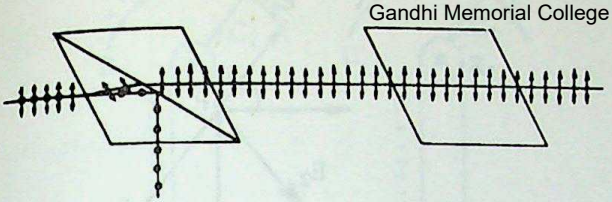


Nicol I as Polariser Nicol II as Analyser

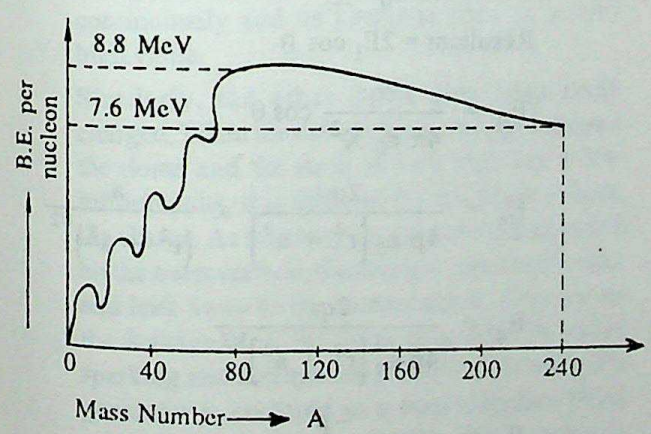
The first Nicol prism acts as polariser and second as analyser. On rotating, the second Nicol intensity varies as

$$I = I_0 \cos^2 \delta/2$$

where δ = Angle between polariser and analyser. The phenomenon of polarisation can be shown only by transverse waves, and thus, light is transverse in nature.

Q. 24 Draw the curve showing variations in binding energy per nucleon with mass number. Explain the release of energy in the processes of nuclear fission and fusion on the basis of this curve. 3

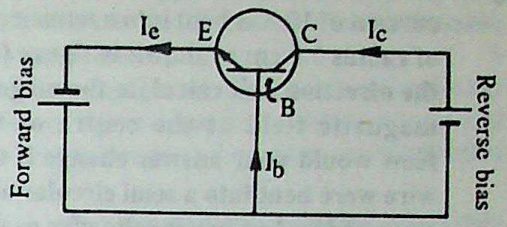
Ans. The middle order nuclei having larger B.E per nucleon are more stable, and hence, when a heavier nucleus like $_{92}U^{235}$ breaks into two small nuclei like Ba and Kr the mass of the product nuclei is less than the reacting mass. The difference ≈ 200 MeV is release per fission.



Similarly, when two or more smaller nuclei cause fusion, the mass of the product nuclei is less than the fusing nuclei and the difference (mass defect) is released in the form of fusion energy.

Q. 25 With a proper circuit diagram, show the biasing of a NPN transistor. Explain the movement of charge carriers through different parts of a transistor. Hence, show that $I_e = I_b + I_c$. 3

Ans.

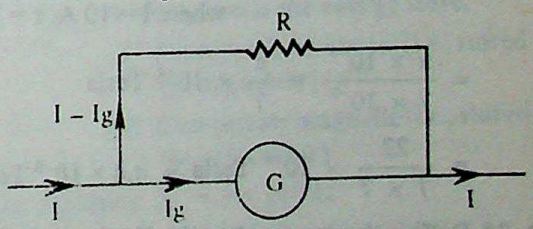


The above figure shows that the emitter (E) base (B) is forwardly biased and base (B) collector (C) is reverse biased. The number of majority carrier crossing the barrier will depend on the applied forward bias. Since, the base layer is very thin so there is a small possibility of majority carriers from E region to combine with the majority carrier of the base region. So, most of the majority carrier from E region pass into the collector region through the base region. A small current does exist in E-B circuit. The reverse biasing attracts the majority carriers from E region. These majority carriers constitute current in the collector circuit. Thus, in transistor, the output is controlled by input.

$$\therefore I_e = I_b + I_c.$$

Q. 26 A galvanometer coil has a resistance of 30 ohm and meter shows full scale deflection for a current of 2.0 mA. Calculate the value of resistance required to convert it into an ammeter of range 0 to 1A. Also calculate the net resistance of the ammeter. 3

Ans. $G = 30\ \Omega$, $I_g = 3 \times 10^{-3}$A, $R = ?$



$I = 1$ A

$$R = \frac{I_g G}{I - I_g} = \frac{3 \times 10^{-3} \times 30}{1 - 3 \times 10^{-3}}$$

$$= \frac{900 \times 10^{-3}}{2.997} = \frac{0.9}{2.997} = 0.3\ \Omega.$$

$$\therefore \text{Net resistance of ammeter} = \frac{30 \times 0.3}{30 + 0.3}$$

$$= \frac{9}{30.03} = 0.299\ \Omega.$$

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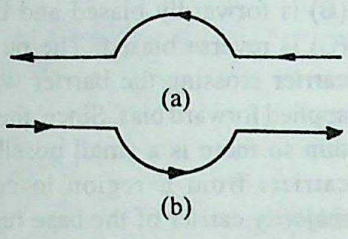
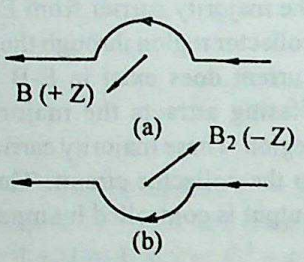
Q. 27 A thick straight copper wire carrying a current of 10 A is bent into a semicircular arc of radius 7.0 cm as shown in figure (a). State the direction and calculate the magnitude of magnetic field at the centre of the arc. How would your answer change if the same wire were bent into a semi circular arc of the same radius but in opposite way as shown in fig. (b)? 3



Ans.



Field in the first case (a) will point towards us and second case (b) away from us. Both the directions are perpendicular to the plane of the paper.

$$B_1 = B_2 = \frac{\mu_0 I}{4r} = \frac{4\pi \times 10^{-7} \times 10}{4 \times 7 \times 10^{-2}}$$

where I = 10 A, r = 7 cm

$$= \frac{\pi \times 10^{-6}}{7 \times 10^{-2}} = \frac{\pi}{7} \times 10^{-4} \text{ Tesla}$$

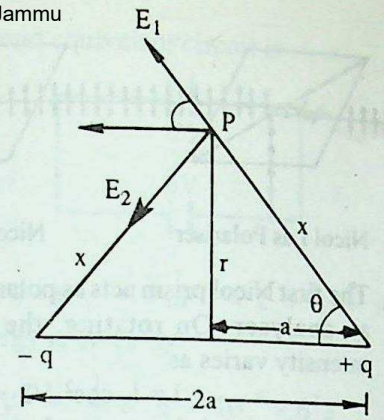
$$= \frac{22}{7 \times 7} \times 10^{-4} \text{ Tesla} = 4.4 \times 10^{-5} \text{ Tesla.}$$

Q. 28 Define the terms electric dipole and dipole moment. Derive an expression for the electric field intensity at a point on equatorial line of a dipole. 5

or

With the help of a labelled diagram, explain the construction and working of a Van De Graaff generator. Mention its use.

Ans. Electric Dipole : Two equal and opposite charges separated by a small distance are said to constitute an electric dipole.



Dipole moment : The product of the magnitude of one charge and the separation between the charges is called the dipole moment. It is a vector quantity and is directed from the negative charge to the positive one and has the unit of coulomb metre.

Let the two charges –q and +q be separated by a small distance 2a. We want to find the field intensity at a point P lying on the equatorial line of this dipole.

Dipole moment : $q \times 2a = 2qa$

$$E_1 = \frac{1}{4\pi \epsilon_0} \frac{q}{X^2}, \qquad E_2 = \frac{1}{4\pi \epsilon_0} \frac{q}{X^2}$$

Resultant $= 2E_1 \cos \theta$

$$E_q = \frac{2q}{4\pi \epsilon_0 X^2} \cos \theta$$

$$E_q = \frac{2q}{4p \epsilon_0 \left[r^2 + a^2\right]} \times \frac{a}{\left(r^2 + a^2\right)^{1/2}}$$

$$E_q = \frac{2qa}{4p \epsilon_0 \left[r^2 + a^2\right]^{3/2}}$$

$$E_q = \frac{-p}{4p \epsilon_0 \left[r^2 + a^2\right]^{3/2}}$$

OR

Van De Graaff's Generator : It consists of a conical copper dome D as shown in fig. R_1 and R_2 are two rollers driven electrically with the help of an electric motor. A conveyor belt made of rubber of silk is fixed over the rollers. C_1 and C_2 are two sharp metal spikes in the form of combs. The lower spike C_1 is connected to the

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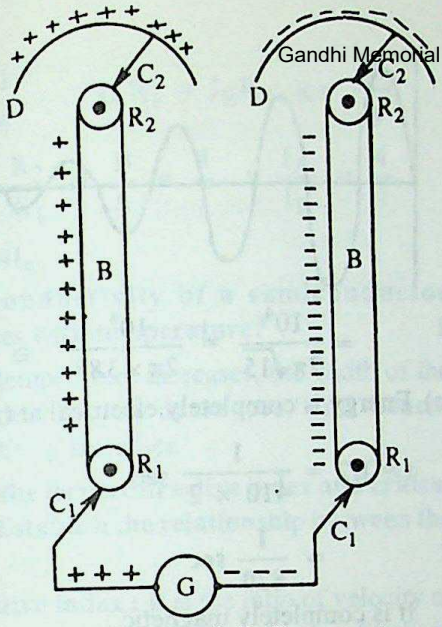


terminal of 20,000 volt D.C. generator and the upper spike C_2 is connected to the metal dome. Due to the action of points the lower spike C_2 spray the electric charge on the belt. This + ve charge is continuously carried by the belt upto the top. At the spike C_2 due to electrostatic induction the dome gets positive charge and the spikes get negative charge. The +ve charge on the belt gets neutralized by the -ve charge on the spikes. Thus, the dome gets the charge continuously and its potential rises to a very high value.

Similarly, the other dome gets negatively charged. When the difference in voltage between the dome and the earth is very high say a few million volts, it is difficult for the dome to hold the charge. As the charge is very closely crowded on the outer surface, the charges repel each other and leak away to the surroundings. Sometimes the leakage is in the form of spark. To avoid sparking and leakage the entire Van de Graaff's generator is enclosed in a steel chamber filled with nitrogen at high pressure. The process is continuous and when the charge on the dome builds up, its voltage increases with respect to earth.

$q = CV, \quad C = 4\pi \in_0 R$

$$\sigma \propto \frac{1}{R}$$

$R \to 0, \ \sigma \to \infty$

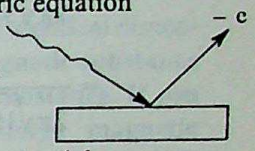
Q. 29 What is photoelectric effect? Explain laws of photoelectric emission. Give two applications of photoelectric cell. 5

Ans. The electrons ejected out of the metal under the action of light are known as photoelectrons and this phenomenon is known as **photoelectric effect.**

(i) A substance shows photoelectric effect only if the incident radiation has frequency above threshold.

(ii) The maximum energy of emitted photons depends only on the frequency of light and is nothing to do with intensity.

Einstein's photoelectric equation



$$h\nu = f_0 + \frac{1}{2} mv^2_{max}$$

$$h\nu = f_0 + ev_0$$

where v_0 = stopping potential.

Uses of photo cell :

(i) It can be used in Burglar Alarm.

(ii) It can be used in automatic switch on and switch off of street lights.

Q. 30 An LC circuit contains a 3mH inductor and a 50 μF capacitor with an initial charge of 10mC. The resistance of the circuit is negligible. Assume the instant the circuit is closed to be t = 0

(a) What is the total energy stored initially?

(b) What is the frequency and time period of the LC oscillations?

(c) At what time is the energy store.

(i) Completely electrical (i.e., stored in the capacitor)

(ii) Completely magnetic (i.e., stored in the conductor) 5

Ans. (a) Here, $L = 3 \times 10^{-3}$ H

$C = 50\ \mu F = 50 \times 10^{-6}$ F

$q_0 = 10 \times 10^{-3}$ C

$$E = \frac{q^2}{2C} = \frac{(10 \times 10^{-3})^2}{2 \times 50 \times 10^{-6}}$$

$$= \frac{100 \times 10^{-6}}{100 \times 10^{-6}} = 1 \text{ J.}$$

$\therefore$ Initial energy on the capacitor at t = 0,

i.e., 1 J.

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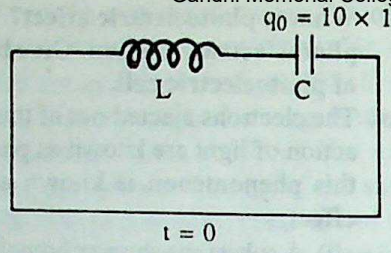
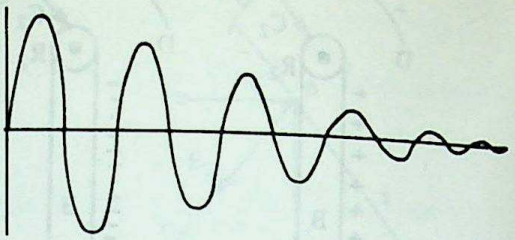


(b) $f = \dfrac{1}{2\pi\sqrt{LC}}$, i.e., natural frequency of LC oscillation.

$$f = \frac{1}{2\pi\sqrt{3 \times 10^{-3} \times 50 \times 10^{-6}}}$$

$$= \frac{1}{2\pi\sqrt{150 \times 10^{-9}}} = \frac{1}{2\pi\sqrt{15 \times 10^{-8}}}$$



$$= \frac{10^4}{2\pi\sqrt{15}} = \frac{10^4}{2\pi \times 3.88} \cong 410 \text{ Hz.}$$

(c) Energy is completely electrical at t = 0 and at

$$t = T/2 = \frac{1}{410 \times 2} \text{ sec}$$

$$= \frac{1}{820} \text{ sec}$$

It is completely magnetic

C.B.S.E. Sample Paper II 1996

Time allowed : 3 Hours **Maximum Marks 70**

General Instructions : Same as Sample Paper I.

Q.1 Define atomic mass unit (a.m.u.). Write the energy equivalent of atomic mass unit in MeV. 1

Ans. One atomic mass unit (a.m.u.) is defined as $\frac{1}{12}$ th of the mass C_6^{12} isotope of carbon.

1 a.m.u. = 931 MeV.

Q. 2 Why does the electrical field inside a dielectric decrease when it is placed in an external electric field? 1

Ans. This is due to polarisation which results into an electric field opposite in direction to the external electric field.

$E = \dfrac{\sigma}{\epsilon_0}$ in vacuum and $E' = \dfrac{\sigma}{K\epsilon_0}$ inside dielectric (K > 1)

Q. 3 State any rule which relates the direction of electric current and the direction of the accompanying magnetic field. 1

Ans. Right hand thumb rule. It states that if we hold the thumb of right hand mutually perpendicular to the grip of the fingers such that the curvature of the finger represents the direction of the current in the wire loop then the thumb of the right hand will point in the direction of the magnetic field near centre of the current loop.

Q. 4 How are voltages across L and C in a series circuit out of phase ? 1

Ans. Pure inductance (L) causes current to lag behind the voltage by $\pi/2$, whereas pure capacitance causes current to lead the voltage by $\pi/2$. Thus, the voltages across inductance and capacitance have a phase difference of π, i.e., they are in opposite phase.

Q. 5 Arrange the following radiations in descending order of their wavelength. Radio waves, X rays. Ultra violet rays, and Red light. 1

Ans. Radio waves > Red light > Ultra violet rays > X rays.

Q. 6 When transistor is used as an oscillator, why is it necessary to feedback energy to LC circuit ? 1

Ans. This is done, in order to compensate for loss caused by the resistance in LC oscillators.

Q. 7 You are provided with two fuse wires A and B having cross-sectional areas in the ratio of 1 : 4. Which one of the two can withstand more current and by what factor? 1

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Ans. $\frac{A}{B} = \frac{1}{4} \quad \therefore I_A R_1 = I_B R_2, R = \frac{\rho L}{A}$

$\frac{I_A}{I_B} = \frac{R_2}{R_1} = \frac{B}{A} = \frac{4}{1} \quad \therefore \frac{I_A}{I_B} = \frac{4}{1}$

$\therefore I_A = 4I_B.$

Q. 8 Why conductivity of a semiconductor increases with temperature? 1

Ans. As the temperature increases, the width of the forbidden region decreases, and hence, conductivity increases.

Q. 9 Define the terms refractive index and critical angle. Establish the relationship between the two. 2

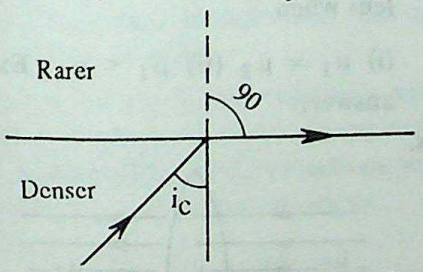
Ans. **Refractive index :** It is the ratio of velocity of light in one medium to the velocity of light in another medium.

$\frac{v}{v'} = {}^1\mu_2$

Also by Snell's law $\frac{\sin i}{\sin r} = {}^1\mu_2$

Critical angle : is that angle in denser medium for which refraction angle is 90° in the rarer medium.

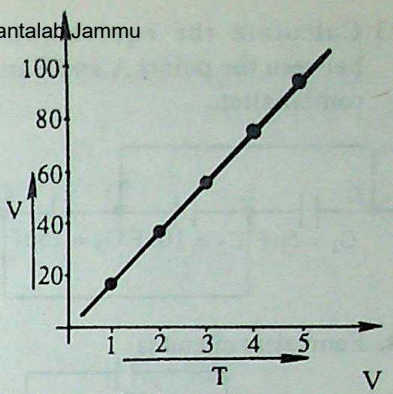
$\therefore \sin i_c = \frac{1}{\mu}$ or $\mu = \frac{1}{\sin i_c}$



Q. 10 Draw V-I graph using the following data : 2

Current I (A)	Voltage V (volt)
1.0	19.7
2.0	39.4
3.0	59.4
4.0	78.5
5.0	98.6

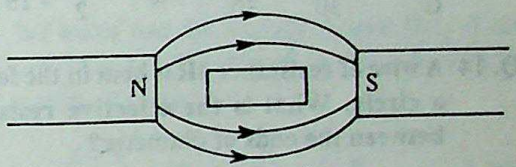
What conclusion can you draw from the graph?



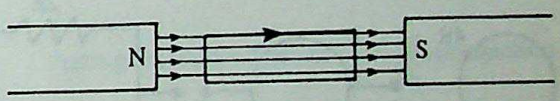
Ans. It is an ohmic resistance as $\frac{V}{I}$ is a constant.

Q. 11 Supose you have two bars of identical dimensions one made of para magnetic substance and other of dia magnetic substance. If you place these bars along a uniform magnetic field, show diagrammatically what modification in the field would take place in each case. 2

Ans.



Paramagnetic



Diamagnetic

Q. 12 What are thermal neutrons? Why are neutrons considered as ideal particles for nuclear fission? 2

Ans. Thermal neutrons are the low energy neutrons or slow moving neutrons. Their energy $\simeq \frac{1}{40}$ eV and the velocity is $\simeq 2.2$ km/s which corresponds to the velocity of random motion atoms and molecules in a gas at room temperature.

When such neutrons strike a fissionable material the unstable state causes breaking of composite nucleus with the release of more neutrons.

$${}_{92}U^{235} + {}_0n^1 \rightarrow {}_{92}U^{236} \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3_0n^1 + 200MeV$$

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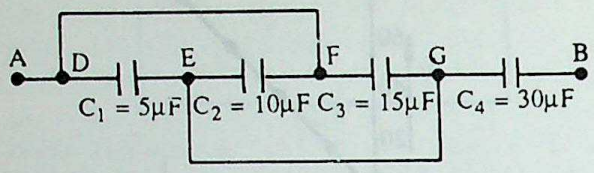
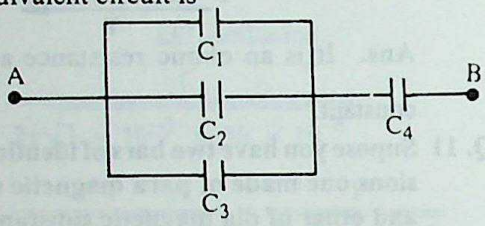
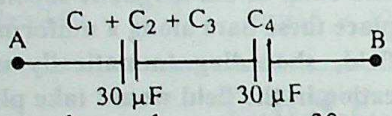
Q. 13 Calculate the equivalent capacitance between the points A and B in the following combination. 2



Ans. Equivalent circuit is

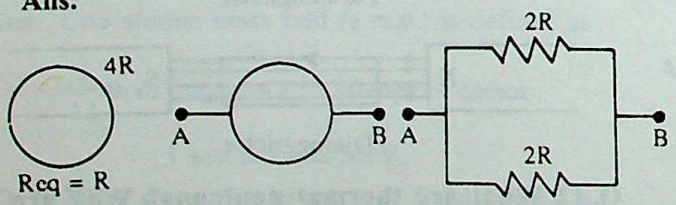




$$\frac{1}{C_{eq}} = \frac{1}{30} + \frac{1}{30} \text{ or } C_{eq} = \frac{30}{2} = 15\ \mu F.$$

Q. 14 A wire of resistance 4R is bent in the form of a circle. What is the effective resistance between the ends of diameter? 2

Ans.



$R_{eq} = R$

$\therefore$ The effective resistance is R.

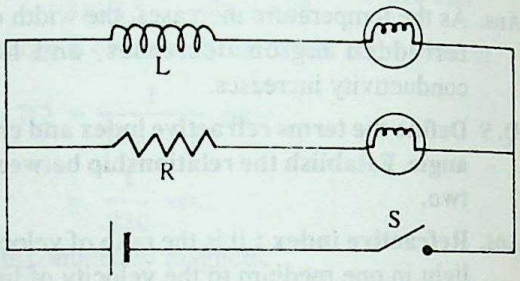
Q. 15 A girl has a bar magnet of pole strength qm and magnetic moment m. If she cuts the magnet into two equal halves by cutting (i) transverse to its length and (ii) along its length, what will be the pole strength and the magnetic moment of each piece? 2

Ans. In the case of transverse cutting pole strength does not change, whereas the dipole moment of each piece is half of the uncut magnet. In case of cutting along length, pole strength as well dipole moment are reduced to half the original value.

Q. 16 Figure below shows an inductor L and a resistor R connected in parallel to a battery through a switch. The resistance of R is the same as that of the coil that makes L. Two identical bulbs are put in each arm of the circuit.

(i) Which of the bulb lights up earlier when S is closed?

(ii) Will the bulbs be equally bright after sometime? 2

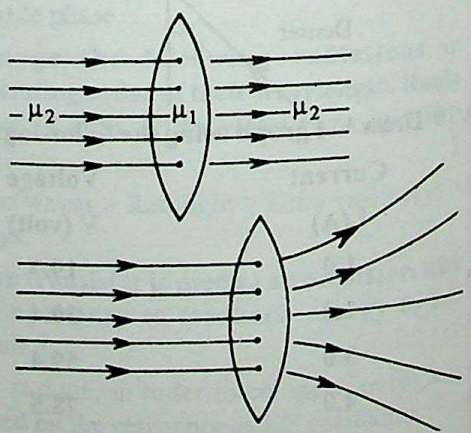


Ans. The bulb in series with the resistance lights up first and the one with inductance will lights later. The intensity of each bulb will be same after some time as the two effective resistances are now equal.

Q. 17 A convex lens made up of a material of refractive index μ_1 is immersed in a medium of refractive index μ_2. Trace the path of a parallel beam of light passing through the lens when

(i) $\mu_1 = \mu_2$ (ii) $\mu_1 < \mu_2$. Explain your answer. 2

Ans.



When $\mu_1 = \mu_2$

(It does not behave as a lens.)

$\mu_1 < \mu_2$ (Acts as divergent lens.)

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Q. 18 The wavelength of the second line of Balmer series in the hydrogen spectrum is 4861 Å. Calculate the wavelength of the first line. 2

Ans. $\frac{1}{\lambda} = RZ^2\left(\frac{1}{4} - \frac{1}{n^2}\right)$, where n = 3, 4, 5, ...

For second line n = 4

$$\frac{1}{\lambda_2} = RZ^2\left(\frac{1}{4} - \frac{1}{4^2}\right)$$

$$\frac{1}{4861} = RZ^2\left(\frac{1}{4} - \frac{1}{16}\right)$$

$$\frac{1}{\lambda_1} = RZ^2\left(\frac{1}{4} - \frac{1}{3^2}\right)$$

as n = 3 for first line.

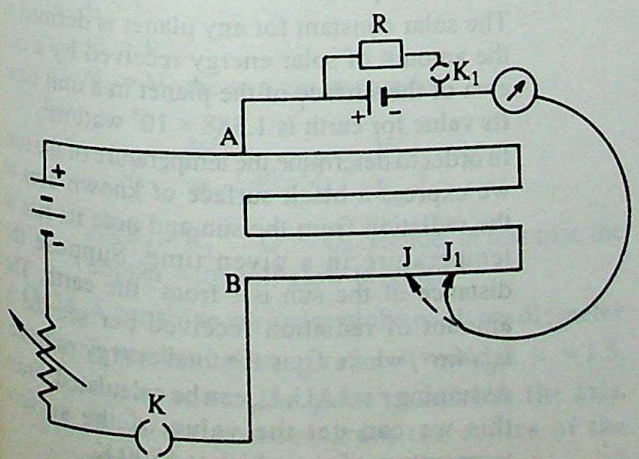
$$\frac{\lambda_1}{4861} = \left(\frac{14-1}{16}\right)\Big/\left(\frac{9-4}{36}\right) = \frac{13}{16} \times \frac{36}{5}$$

$$\therefore \lambda = \frac{4861 \times 13 \times 36}{80} = \mathbf{6562\ Å.}$$

Q. 19 With the help of a circuit diagram, explain how can you find the internal resistance of a primary cell ? Derive the necessary formula. 3

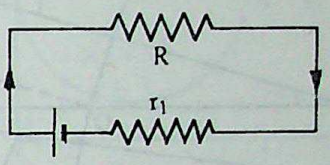
Ans. The internal resistance of the primary cell can be found by using a potentiometer. The circuit diagram is given below.

First close the key K and maintain a suitable constant current in the potentiometer and find out a balance point on the potentiometer. Let L_1 be the length of the potentiometer.



$\therefore E = KL_1$ ... (1)

Close key K_1 and K so that the resistance R is introduced in the cell. Again find out the position of the new balanced length on the potentiometer. Let it be L_2



$\therefore (E - Ir) = KL_2$ ... (2)

$\therefore V = KL_2$ ... (3)

Dividing (3) & (1)

$$\frac{E}{V} = \frac{L_1}{L_2}$$

We know that the internal resistance r_1 of the cell of e.m.f. E when R is connected in its circuit, is given by

$$r_1 = \frac{E-V}{V} \times R = \left(\frac{E}{V} - 1\right)R \quad \text{... (4)}$$

Putting the values from in $\frac{E}{V} = \frac{L_1}{L_2}$ in equation 4, we get

$$r_1 = \left(\frac{L_1}{L_2} - 1\right)R = \frac{L_1 - L_2}{L_2}R.$$

Thus, knowing the values of L_1, L_2 and R, r_1 can be calculated.

Q. 20 State Huygen's principle. Prove Snell's law by using this principle. 3

Ans. According to Huygen's principle.

1. Every point on the primary wavefront is a source of disturbance and gives rise to secondary wavelets.
2. A surface touching the secondery wavelets, tangentially in the forward direction at any instant gives the new wavefront at the instant. This is called secondary wavefront.

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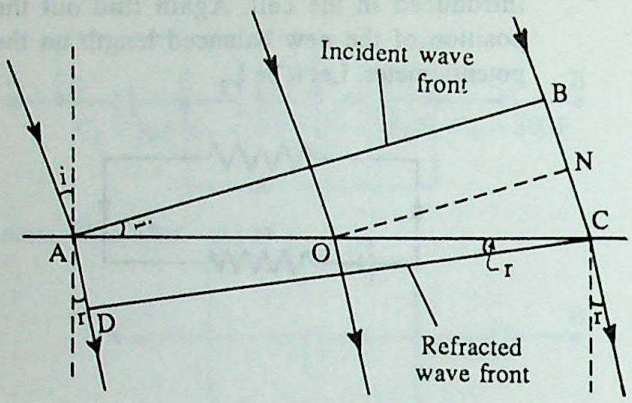
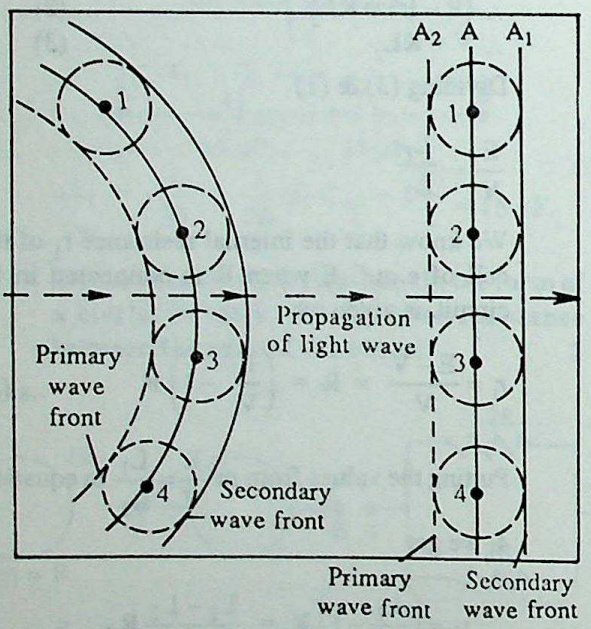
Snell's Law





Let AB be an incident wavefront in medium 1 (speed of light C_1) DC is the refracted wavefront (speed of light C_2)

$BC = C_1 t$

$AD = C_2 t$

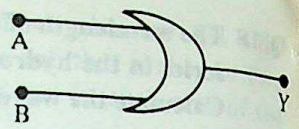
$$\frac{\sin i}{\sin r} = \frac{BC/AC}{AD/AC} = \frac{BC}{AD} = \frac{C_1}{C_2}$$

$$\mu_2 = \frac{\sin i}{\sin r} = \frac{C_1}{C_2}$$ which is Snell's Law

Q. 21 Draw the logic symbol and truth table of an OR gate. Describe its realisation with the circuit diagram using semi conductor diode. 3

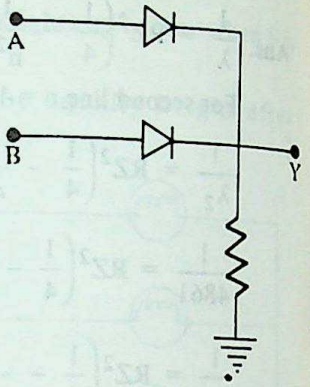
Ans. OR gate

Logic symbol



Boolean equation

$Y = A + B$



Truth Table

A	B	Y
0	0	0
1	0	1
0	1	1
1	1	1

When either A or B both are high, the diode/diodes will conduct and output is high. The output will be low when both the diodes have low inputs at A and B, and thus, output at y is also low.

Q. 22 How will you determine the temperature of the sun. Derive the necessary formula. 3

Ans. The temperature of the sun can be calculated by using any radiometer :

Using Stefan's Law

$E = \sigma T^4$, where, σ is Stefan's constt. and E is the thermal energy emitted per second per unit area of the planet.

The solar constant for any planet is defined as the amount of solar energy received by a unit area of the surface of the planet in a unit time. Its value for earth is 1.388×10^3 watt/m^2.

In order to determine the temperature of the sun, we express a black surface of known area to the radiation from the sun and note its rise in temperature in a given time. Suppose the distance of the sun is r from the earth. The amount of radiation received per second is $L_0/4\pi r^2$, where L_0 is the total energy radiated. Assuming $r = 1AU$, L_0 can be calculated. From this we can get the value of the surface temperature of sun which is 5800 K.

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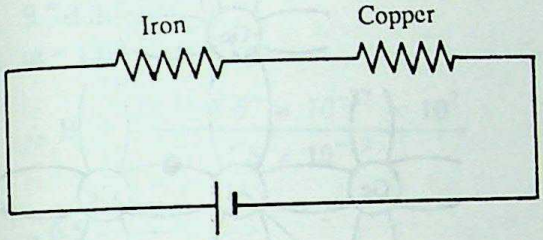
Q. 23 A student has two wires of Iron and Copper of equal length and diameter. He first joins the two wires in series and passes an electric current through the combination which increases gradually. After that he joins the two wires in parallel and repeats the process of passing current. Which wire will glow first in each case and why? 3

Ans. Case I



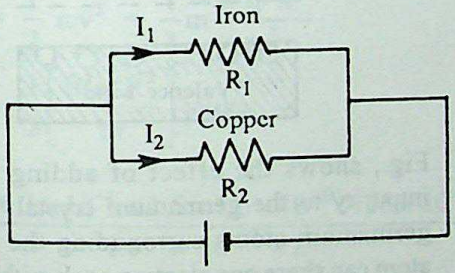
For the same current.

$Q_1 = I^2R_1t$

$Q_2 = I^2R_2t$

as $R_1 > R_2$, the iron wire will glow more in series.

Case II



$I_1 < I_2$

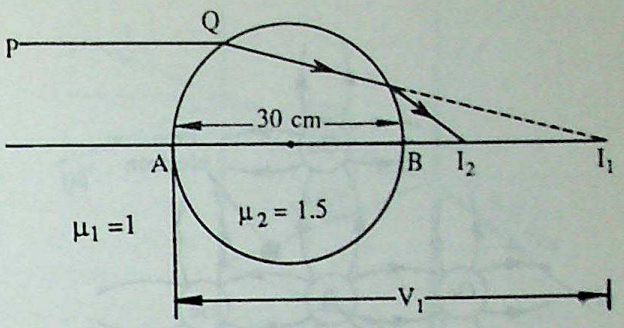
$R_1 > R_2$

$V_1 = V_2$ the two are in parallel.

$$\therefore Q_1 = \frac{V_1^2}{R_1}t \text{ and } Q_2 = \frac{V_2^2}{R_2}t$$

As $R_1 > R_2$ $\therefore Q_1 < Q_2$. Hence, in this case the copper wire will glow brighter.

Q. 24 A sunshine recorder globe of 30 cm diameter is made of glass of refractive index $\mu = 1.5$. A ray enters the globe parallel to the axis. Find the position from the centre of the sphere where the ray crosses the axis. 3



For refraction at the first surface A.

$$\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$$

$\mu_1 = 1, u = \infty, v = v_1$

$$\therefore \frac{\mu_2}{v_1} = \frac{\mu_2 - 1}{15}$$

$$\therefore v_1 = \frac{1{\cdot}5 \times 1{\cdot}5}{(1{\cdot}5-1)} = \frac{1{\cdot}5 \times 1{\cdot}5}{0{\cdot}5} = 45$$

$\Rightarrow BI_1 = 15$ cm

Now, I_1 will act as an object for the surface B.

$\therefore u = BI_1, v_2 = 1{\cdot}5, \mu'_1 = 1{\cdot}5, \mu'_2 = 1$

u = –15 cm.

For surface B

$$\frac{\mu'_2}{v_2} - \frac{\mu'_1}{u_2}E = \frac{(\mu'_2 - \mu'_1)}{R}$$

$$\frac{1}{v_2} + \frac{1.5}{15} = \frac{-0.5}{15}$$

$$\frac{1}{v_2} = \frac{-0.5}{15} - \frac{1.5}{15} = \frac{-2}{15}$$

$\therefore v_2 = -7.5$. Hence, $BI_2 = 7.5$

$OI_2 = 15 + 7.5 =$ **22.5 cm.**

Q. 25 Differentiate between n-type and p-type semiconductors on the basis of energy band diagrams. Explain the process of conductors in both type of materials. 3

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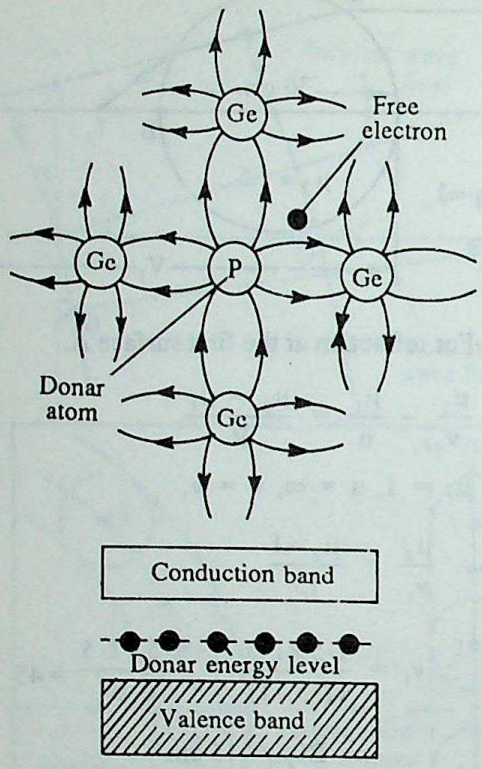
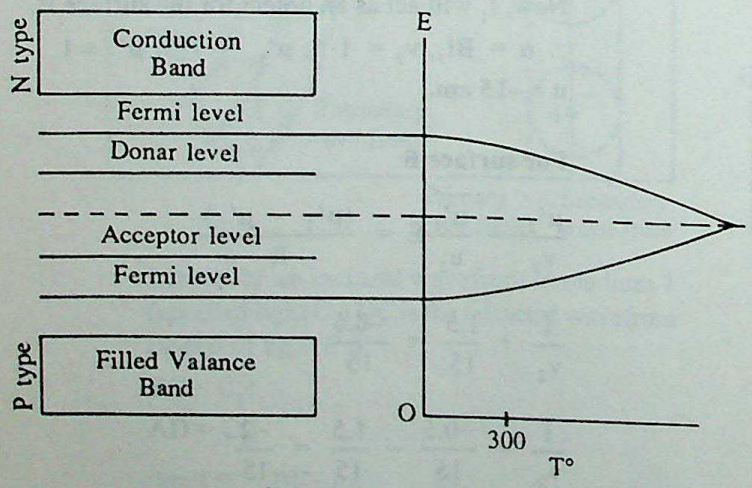
Ans. N-type semiconductor :





By adding a pentavalent impurity phosphorus to germanium crystal we get, N type semiconductor. When an impurity atom with 5 valence electrons is added to germanium crystal it replaces one of the germanium atom. Four of the five valence electrons form covalent bonds with one each valence electron of four Ge atoms and the fifth valence electron becomes free to move in the crystal structure. This free electron acts as a charge carrier. Hence, by introducing impurity in pure Ge, the number of free electrons increases, and hence, the conductivity of the crystal increases.

P-type semiconductor :

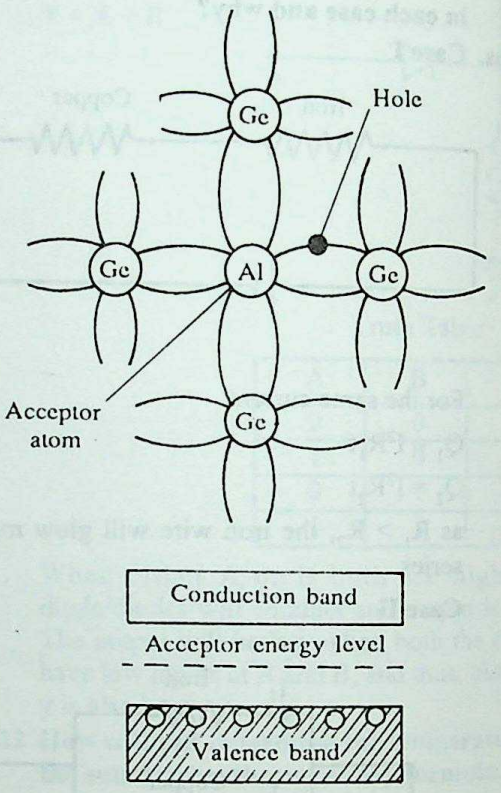


Fig., shows the effect of adding trivalent impurity to the germanium crystal. The four germanium atoms surrounding the impurity atom can share one electron each with impurity atom which has got three valence electrons. In an attempt to have 8 electrons in valence shell, the impurity atom robs one of the nearby covalent bond of one electron. The valence shell of the impurity atom gets completed but a hole is created in the covalent bond from which electron has been robbed. Thus, for every trivalent impurity atom added, an extra hole will be created. The Ge crystal so obtained is called P type as it contains free holes. Here, the majority carriers are holes.

Q. 26 The frequency of cyclotron oscillator is 10^7 Hz. What should be the operating magnetic field for accelerating protons? If the radius of the dees of the cyclotron is 6×10^{-1}m.

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Calculate the energy of the proton beam produced by it in MeV. ($e = q = 1.6 \times 10^{-19}$ C; $m = 1.67 \times 10^{-27}$ kg; 1 MeV = 1.602×10^{-23} J) **3**

Ans. $B = \dfrac{2\pi mf}{q}$

f = frequency of cyclotron = 10^7 Hz.

$q = 1.6 \times 10^{-19}$C

$m = 1.67 \times 10^{-27}$ kg

$$\therefore B = \frac{2\pi \times 1.67 \times 10^{-27} \times 10^7}{1.6 \times 10^{-19}}$$

$$= 6.5 \times \frac{10^{-1}}{1}$$

For energy of proton beam

$$\frac{mv^2}{R} = Bqv \therefore \frac{mv}{R} = Bq$$

$$\therefore v = \left[\frac{BqR}{m}\right]$$

$R = 6 \times 10^{-1}$ m

$$E = \frac{1}{2}mv^2 = \frac{1}{2}m\frac{B^2q^2R^2}{m^2}$$

$$= \frac{1}{2}\left[\frac{B^2q^2R^2}{m}\right] \text{ joules}$$

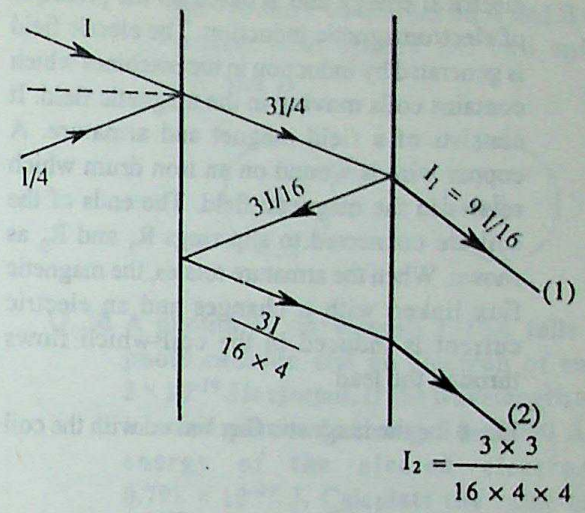
$$E = \frac{6.3 \times 6.3 \times 10^{-2} \times 1.6 \times 1.6 \times 10^{-38} \times 36 \times 10^{-2}}{1.67 \times 10^{-27} \times 2}$$

$$= \frac{6.3 \times 6.3 \times 1.6 \times 1.6 \times 36 \times 10^{-42}}{1.67 \times 10^{-27} \times 2}$$

$= 1095 \times 10^{-15}$ J

Q. 27 A narrow monochromatic beam of light of intensity I is incident on a glass plate. Another identical glass plate is kept close to the first one and parallel to it. Each plate reflects 25% of the incident light and transmits the remaining. Calculate the ratio of the minimum and maximum intensity in the interference pattern formed by two beams obtained after the reflection from each other. **3**

Ans.



$$I_2 = \frac{3 \times 3}{16 \times 4 \times 4}$$

$$I_1 = \frac{9I}{16}$$

$$I_2 = \frac{9I}{256}$$

The interference is between ray 1 and 2

$$\therefore \frac{I_1}{I_2} = \frac{16}{1} \Rightarrow \frac{a_1^2}{a_2^2} = \frac{16}{1} \text{ or } \frac{a_1}{a_2} = \frac{4}{1}$$

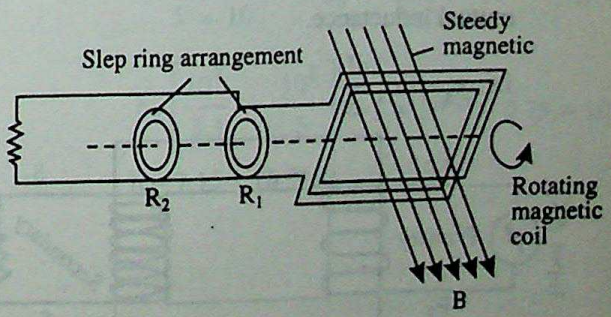
$$\frac{I\,max.}{I\,min.} = \frac{(a_1 + a_2)^2}{(a_1 - a_2)^2} = \frac{(4a_2 + a_2)^2}{(4a_2 - a_2)^2} = \frac{25}{9}$$

Q. 28 With the help of a labelled diagram, explain the principle, construction and working of an a.c. generator. **5**

or

With the help of a labelled diagram explain the construction working of a step-up transformer. Why is the core laminated?

Ans. A.C. generator :



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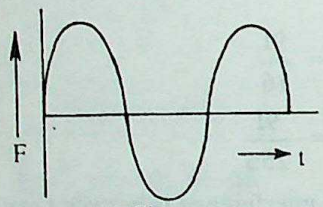
It is a device to convert mechanical energy into electrical energy and is based on the principle of electromagnetic induction. The elecric field is generated by induction in the machines which contains coils moving in the magnetic field. It consists of a field magnet and armature. A copper wire is wound on an iron drum which rotates in the magnetic field. The ends of the coil are connected to slip rings R_1 and R_2 as shown. When the armature rotates, the magnetic flux linked with it changes and an electric current is induced in the coil which flows through the lead.

Let ϕ be the magnetic flux linked with the coil



Sine curve

$$\phi = N\vec{B}\vec{A}$$

$\phi = NBA \cos\theta = NBA \cos \omega t$

Using Faraday's Law of electromagnetic induction.

$$e = -\frac{d\phi}{dt} = NBA\,\omega \sin \omega t$$

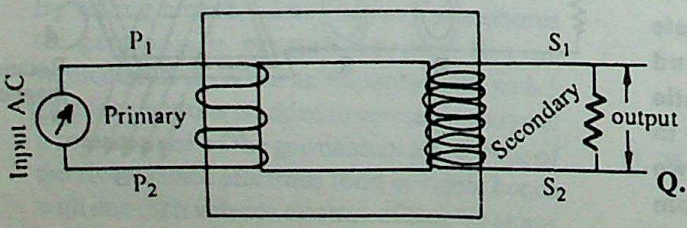
Hence, an alternating e.m.f. is generated in the A.C. generator.

OR

Step-up Transformer :

The principle of the transformer is based on mutual inductance.

i.e., $e_s = m_{21}\frac{dI_1}{dt}$



A step-up transformer is a device to convert alternating current at low voltage into high voltage.

It consists essentially of two coils electrically insulated from each other and are wound on the same silicon-iron core. The coil in which energy is supplied, is called the primary, and that from which energy is delivered to the outer circuit is called secondary.

As the current in the primary varies, the magnetic flux linked with P_1P_2, and hence, with a secondary S_1S_2 changes. Due to self inductance, an e.m.f. is induced in P_1P_2 and due to mutual induction, an e.m.f. is induced in S_1S_2.

Let n_p be the no. of turns in the primary P_1P_2

Ep—alternating e.m.f. fed to P_1P_2 at instant t.

$\frac{d\phi}{dt}$ = rate of change of magnetic flux linked

with P_1P_2 i.e., $-n_p\frac{d\phi}{dt}$ or $Ep = -n_p\frac{d\phi}{dt}$ ...(i)

If there is no leakage of magnetic flux, then the rate of change of magnetic flux through each turn of S_1S_2 is $\frac{d\phi}{dt}$. If n_s is the number of turns then e.m.f. induced in the secondary due to mutual induction is

$$Es = -n_s\frac{d\phi}{dt} \quad \text{... (ii)}$$

Dividing (ii) and (i), we get

$$\frac{Es}{Ep} = \frac{n_s}{n_p} = K,$$

where K is called transformer ratio. For step-up $E_s > E_p$, hence, $K > I$

Hence, $n_s > n_p$

The core is laminated in order to minimise the eddy current losses. Eddy currents are set up in metals due to the varying magnetic field.

Q. 29 A glass rubbed with silk is brought close to two uncharged spheres in contact with each other inducing charges on them as shown in figure.

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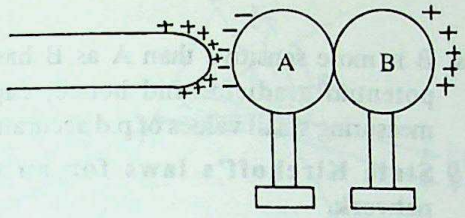


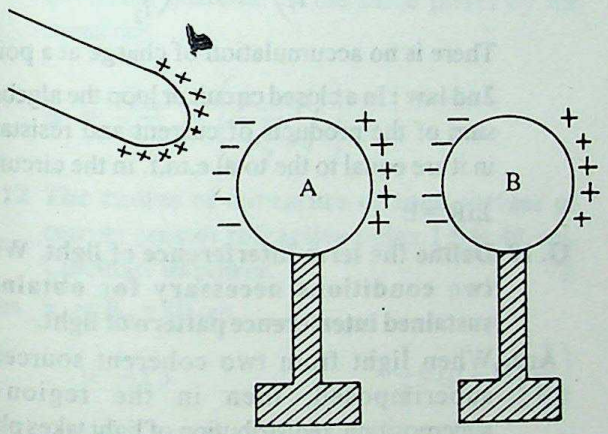
Show with a diagram in each case what happens when :

(i) The spheres are slightly separated?

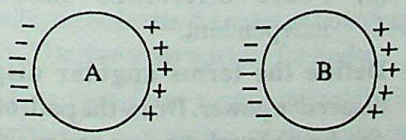
(ii) The glass rod is subsequently removed?

(iii) The spheres are separated apart. **5**

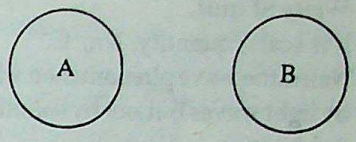
Ans. (i) When the spheres are slightly separated, the induced charges are shown in the figure.



(ii) As the glass rod is removed, the distribution of charges remains the same on A and B.



(iii) When A and B are kept at a large distance, the -ve and + ve charges on A and B unite, hence, neutralising the two spheres A and B .



Q. 30 A photon of wavelength 3310Å falls on a photo cathode and an electron of energy 3×10^{-19} J is ejected. If the wavelength of the incident photon is changed to 5000 Å, the energy of the ejected electron is 0.791×10^{-19} J. Calculate the value of the Planck's constant and the threshold wavelength of the photon. **5**

Ans. $\lambda_1 = 3310\text{Å} = 3.31 \times 10^{-7}\ \text{m}$

$$E_1 = \frac{1}{2}mv^2_{max} . = 3 \times 10^{-19}\ \text{J}$$

$$hv = \phi_0 + \frac{1}{2}mv^2_{max.}$$

$$\frac{hc}{\lambda_1} = \phi_0 + E_1$$

$$\text{or } \frac{hc}{3.3 \times 10^{-7}} = \phi_0 + 3 \times 10^{-19} \quad \ldots(1)$$

$$\lambda_2 = 5000\ \text{Å} = 5 \times 10^{-7}\ \text{m},$$

$$\frac{1}{2}mv^2_{max} = E_2 = 0.791 \times 10^{-19}$$

$$\therefore \frac{hc}{5 \times 10^{-7}} = \phi_0 + 0.79 \times 10^{-19} \quad \ldots(2)$$

$$hc\left[\frac{10^7}{3.3} - \frac{10^7}{5}\right] = 3 \times 10^{-19} - 0.79 \times 10^{-19}$$

$$h = 7.15 \times 10^{-34}\ \text{Js}$$

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C.B.S.E. Sample Paper III 1996

Time allowed : 3 Hours **Maximum Marks 70**

General Instructions : Same as Sample Paper I.

Q. 1 Is electric flux a scalar or a vector quantity? Write SI unit. 1

Ans. It is scalar quantity, Nm^2C^{-1}.

Q. 2 Name the wave phenomenon which is exhibited by light waves but not by sound waves. 1

Ans. Polarisation.

Q. 3 Two stars A and B have magnitudes of –2 and 2 respectively which of the two is brighter and by how much? 1

Ans. Star A with magnitude –2 is brighter ratio of brightness $= (2.512)^4 = 39.8$.

Q. 4 Will the resistivity of a metallic conductor increase or decrease with the increase in its temperature? Justify your answer. 1

Ans. It will increase and the variation is given below :

$\rho = \rho^0 (1 + \alpha t)$, where α is + ve for conductors.

Q. 5 A student while moving on the surface of earth locates two places where a magnetic needle free to rotate in a vertical plane orients itself in such a way that its axis becomes vertical. Which element of the earth's magnetic field has (a) maximum and (b) minimum value at these places? 1

Ans. (a) Vertical. (b) Horizontal.

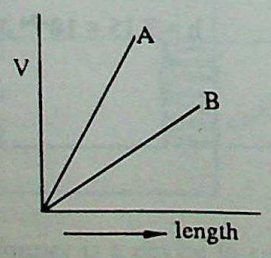
Q. 6 Why are microwaves used in RADAR? 1

Ans. For most efficient operation of RADAR, it requires that the size of the object to be detected should be many times as large as wavelength. Thus, ultra short waves in decimetre, centimetre, and millimetre bands are used.

Q. 7 A current flows in a metallic conductor of uniform cross-section. Wliich one of following quantities is constant along the conductor : Current, current density, drift speed. 1

Ans. Current.

Q. 8 The variation of p.d with length in case of two potentiometer A and B is given alongside. Which one is more sensitive and why? 1



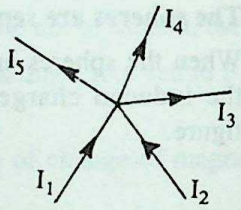
Ans. B is more sensitive than A as B has smaller potential gradient, and hence, capable of measuring small values of p.d accurately.

Q. 9 State Kirchoff's laws for an electric network. 2

Ans. 1st law : The algebraic sum of the currents flowing at a junction point is zero.

i.e., $\Sigma i = 0$

$I_1 + I_2 - I_3 - I_4 - I_5 = 0$



There is no accumulation of charge at a point.

2nd law : In a closed circuit or loop the algebraic sum of the products of current and resistance in it are equal to the total e.m.f. in the circuit.

$\Sigma IR = E$

Q. 10 Define the term interference of light. Write two conditions necessary for obtaining sustained interference pattern of light. 2

Ans. When light from two coherent sources is superimposed, then in the region of superposition, redistribution of light takes place. This is called the interference. For sustained interference, the conditions required are :

(a) Sources must have same frequency and wavelength.

(b) Phase difference should be time independent.

Q. 11 Define the terms angular dispersion and dispersive power. Draw the path of a ray of light passing through a prism and mark the angular dispersion on it. 2

Ans. Angular dispersion : The next figure shows the dispersion of white incident ray by prism. Let δ_v and δ_R are the deviation of violet and red colour respectively.

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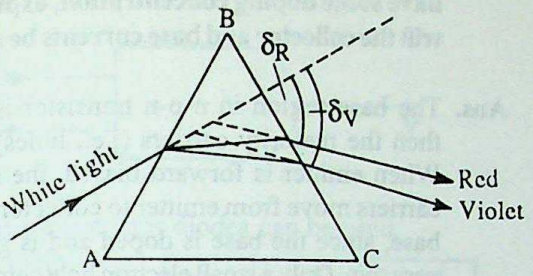


The difference in angles of deviation of any two rays is called the angle of dispersion for those rays. Hence, for violet and red colour angular dispersion.

$$Q_{vr} = \delta_v - \delta_r = (\mu_v - \mu_r) A$$

Dispersive Power : It is the ratio of the dispersion between any two colours to the deviation suffered in the same prism by the mean ray.

$$\omega = \frac{Q_{vr}}{\delta_y} = \left(\frac{\mu_v - \mu_r}{\mu_y - 1}\right)$$

Q. 12 The radius of curvature of each surface of convex lens of refractive index 1·5 is 40 cm. Calculate its power. 2

Ans. $R_1 = R_2 = 40$ cm

$\mu = 1.5$ $\quad \therefore \frac{1}{f} = (\mu - 1)\left(\frac{2}{R}\right)$

$P = \frac{1}{f}$

$\therefore \quad P = (\mu - 1)\left(\frac{2}{R}\right) = \frac{0.5 \times 2}{0.4} = \frac{10}{4} = 2.5$ D

$P = +2.5$ D.

Q.13 How will you estimate the mass of binary system of stars ? Derive appropriate formula. 2

Ans. When two stars form a gravitationally bound system having a common centre, then such a system of stars is called a binary system. Let M_1 and M_2 be masses of such stars, if a is the separation.

$M_1 + M_2 = \frac{4\pi^2 a^3}{GT^2}$ using Kepler's Law

If a is expressed in A.U.

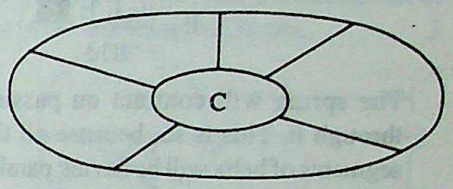
$\therefore M_1 + M_2 = \frac{a^3}{T^2}$ _____ (1)

$M_1 a_1 = M_2 a_2$ _____ (2)

$\therefore \quad a = a_2$ _____ (3)

From these equations M_1 and M_2 can be calculated.

Q. 14 A conductor with a cavity as shown in the figure is given a charge Q. Using Gauss's theorem show that the entire charge Q lies on the outer surface of the conductor. 2



Ans. On drawing any Gaussian (closed) surface; wherein the cavities are there, applying Gauss's theorem

$\vec{E}\vec{ds} = 0 \Rightarrow E = 0$

Hence, the electric field in any region of cavity will be zero. The electric field outside the conductor will alone be non zero and will be due to the charges on the outer surface of the conductor.

Q. 15 A simple voltaic cell has an e.m.f. of 1.0V. Is there a net field inside the cell when (i) circuit is open (ii) circuit is closed and a steady current is drawn from it. Explain your answer in each case. 2

Ans. (i) When the cell is in an open circuit.

Electric field $E_1 = \frac{\varepsilon}{d}$, where ε is the e.m.f. of the cell.

(ii) In a closed circuit

$V' = (\varepsilon - Ir)$

$\therefore \quad E_2 = \frac{\varepsilon - Ir}{d} \quad \therefore E_2 < E_1.$

Q. 16 Suppose a helical spring is suspended from the roof of a room and a very small weight is also hanging from its lower end. What will happen to the spring if a current is passed through it. Give reason in support of your answer. 2

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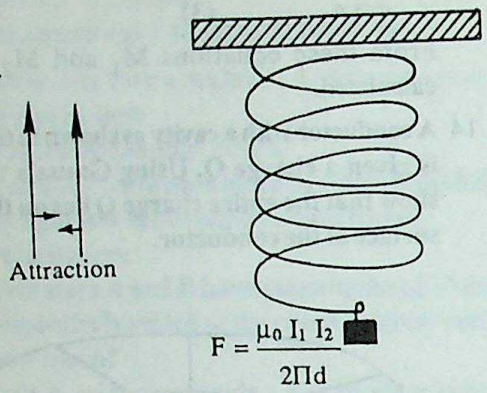
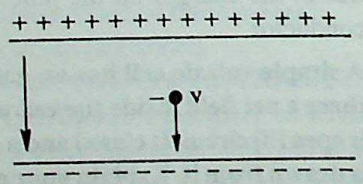
Ans.



The spring will contract on passing current through it. This is so, because all the circular segments of helix will be having parallel currents in the same direction, hence, attraction will take place and the spring contracts.

Q. 17 A charged oil drop falls under gravity with a terminal speed v. The drop is held stationary by applying suitable electric field in a Millikan's set up and is found to carry 2 excess electrons. Suddenly the drop is observed to move upward. Write relevant mathematical equation in support of your answer. 2



Ans. For fall under gravity and presence of air

$$\frac{4}{3}\pi r^3(\rho-\sigma)=6\pi\eta r v_1 \qquad \text{——— (1)}$$

On applying electric field the drop is first held stationary by applying an electric field in the downward direction.

$$2eE-\frac{4}{3}\pi r^3(\rho-\sigma)g=0$$

The drop will start moving again in the upward direction, if it gains extra charge or looses some mass.

In case of gain in mass

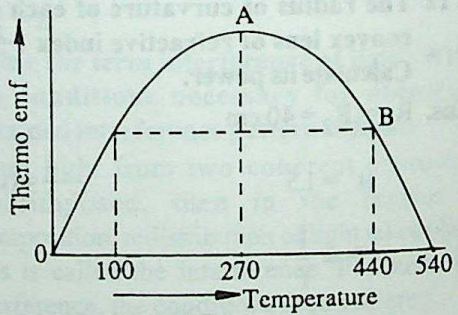
$$eE-\frac{4}{3}\pi r^3(\rho-\sigma)g=6\pi\eta r' v'_2$$

Q. 18 If the emitter and base of a n-p-n transistor have some doping concentration, explain how will the collector and base currents be affected. 2

Ans. The base region in n-p-n transistor is doped, then the majority carriers (i.e., holes) is low. When emitter is forward biased, the majority carriers move from emitter to collector through base, since the base is doped and is generally very thin. Only a small electron hole combination will take place giving rise to weak base current and the most of the majority carriers will reach the collector giving collector current nearly equal to emitter current. Hence, the collector current will be more.

Q. 19 What is Seebeck's effect. Draw a curve to show how thermo e.m.f. varies when the temperature of the hot junction is increased gradually. Show neutral temperature and inversion temperature in the curve. 3

Ans. Seebeck's effect is the phenomenon of generation of an electric current in a thermocouple by keeping its two junctions at different temperatures.



If a graph is plotted between temperature of the hot junction and the thermo e.m.f., the cold junction kept at 0 °C, it is a parabola. The point A represents the neutral temperature. The point B represents the temperature of inversion θ_n is neutral temperature θ_1 is the inversion temperature.

$$E=\alpha\theta+\frac{1}{2}\beta\theta^2,\ \frac{dE}{d\theta}=0 \text{ at } \theta=\theta_n$$

Similarly, $E=0$ at $\theta=0$ and $\theta=\theta_i$

Q. 20 Draw the logic symbol and write the truth table of AND gate with the help of a circuit diagram, describe the realisation of AND gate using semiconductor diodes. 3

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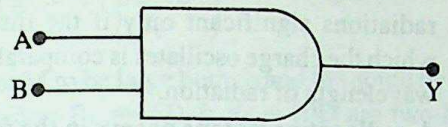
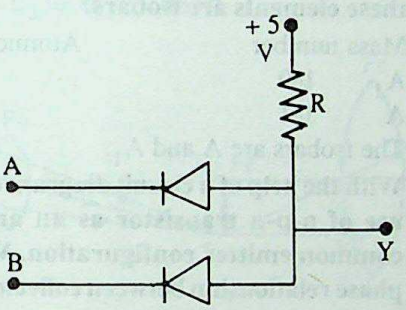
Ans. Y = A.B



The semiconductor diodes can be used.

Truth table

A	B	Y
0	0	0
1	0	0
0	1	0
1	1	1



When either A or B (or both) is grounded diode/diodes conduct, and hence, p.d. across Y and ground is zero. When both A and B are connected high, diodes do not conduct, and hence, Y is at 5V w.r.t. earth, and hence, a high output.

Q. 21 What is meant by the current sensitivity of a moving coil galvanometer? On what factors does it depend? In an exercise to increase current sensitivity of a galvanometer by 25% its resistance is also increased 1.5 times. How will the voltage sensitivity of the meter be affected? 3

Ans. Current sensitivity of a galvanometer is defined as the deflection produced in the galvanometer when a unit current flows through it.

Let θ be the deflection in the galvanometer when current I is passed through it then

$$I_s = \frac{\theta}{I} = \frac{nBA}{K}\left[\because I = \frac{K}{nBA}\theta\right]$$

It depends on the number of turns in the coil (n), the strength of the magnetic field B and A the area of the coil.

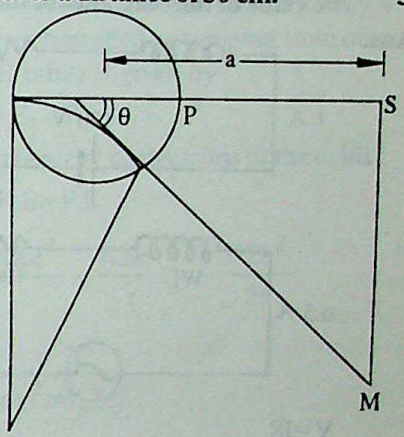
Voltage sensitivity

$$V_s = \frac{\theta}{IR} = \frac{nBA}{KR} = \frac{Is}{R}$$

$$V_s = \frac{25 \cdot 0}{1 \cdot 5} = \frac{50}{3} \simeq 16.67\%$$

Q. 22. An electron beam of initial energy 18 keV moving horizontally is subjected to a horizontal magnetic field of 0.4 G normal to the initial direction. Calculate the vertical deflection of the beam over a distance of 30 cm. 3

Ans.



$E = 18\text{keV} = 18 \times 10^3 \times 1.6 \times 10^{-19}\,\text{J}$

$B = 0.4 \text{ gauss} = 0.4 \times 10^{-4} \text{ tesla}$

$$\frac{1}{2}mv^2 = 18 \times 1.6 \times 10^{-16}$$

$$\therefore mv^2 = 36 \times 1.6 \times 10^{-16}$$

Using $\frac{mv^2}{r} = Bev$

$$\therefore r = \frac{mv}{Be}\ ; \quad \frac{OP}{r} = \frac{SM}{a} = \frac{y}{a}$$

Given,

$r = \frac{mv}{Be}$, $y = ?$ $OP = 2a$

(in the present case)

$$\therefore y = \frac{a \times OP}{r}$$

$$= \frac{15\times10^{-2} \times 2 \times 15 \times 10^{-2}}{mv} \times Be$$

$$y = \frac{15 \times 2 \times 15 \times 0.4 \times 1.6 \times 10^{-27}}{\sqrt{36 \times 1.6 \times 10^{-16} \times 9.1 \times 10^{-31}}}$$

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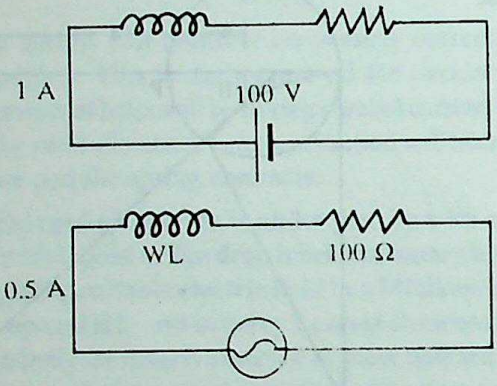
$$= \frac{280 \times 10^{-27}}{\sqrt{524 \cdot 6 \times 10^{-47}}} = \frac{28 \times 10^{-26}}{\sqrt{52 \cdot 46 \times 10^{-46}}}$$

$$= \frac{28 \times 10^{-26}}{724 \times 10^{-23}} \cong 3.86 \times 10^{-3}\,\text{m}$$

$$\cong 4 \times 10^{-3}\,\text{m}$$

Q. 23 When 100V.D.C. is applied across an inductor, a current of 1A flows through it. If the same inductor is connected to a 100V A.C. source the current reduces to 0.5 A. Why is the current reduced in the later case ? Calculate the value of the reactance of the inductor. 3

Ans.



$V = IR$

$100 = 1 \times R \quad \therefore R = 100\,\Omega$

$Z = \sqrt{R^2 + L^2 W^2}$ The current becomes less due to the impedance.

$$\frac{V}{I} = Z$$

$$\therefore I = \frac{V}{Z} = \frac{100}{\sqrt{R^2 + L^2 W^2}} = 0.5$$

$$\therefore \sqrt{R^2 + L^2 W^2} = \frac{100}{0.5} = \frac{1000}{5}$$

$$\therefore R^2 + L^2 W^2 = \left(\frac{1000}{5}\right)^2$$

$$\therefore R^2 + X_L^2 = \frac{10^6}{25}$$

$$\text{or } (100)^2 + X_L^2 = \frac{10^6}{25}$$

$$\therefore X_L^2 = 4 \times 10^4 - 10^4 = 3 \times 10^4$$

$$\therefore X_L = \sqrt{3} \times 10^2\,\Omega.$$

Q. 24 With the help of a schematic diagram explain Hertz's experimental set up for the production of electromagnetic waves. What important conclulsion was drawn from this experiment? 3

Ans. For Hertz's experiment see unit 7.

With this experiment he obtained radiation of wavelength about 6m. These electromagnetic radiations significant only if the distance to which the charge oscillates is comparable to the wavelength of radiation.

Q. 25 A radioactive isotope decays in the following sequence :

$$A \xrightarrow{+1B^0} A_1 \xrightarrow{\propto} A_2$$

If the mass number and the atomic number of A_2 are 176 and 71 respectively, find the mass number and atomic number of A_1 and which of these elements are isobars? 3

Ans.

	Mass number	Atomic number
A_1	180	73
A	181	73

The isobars are A and A_1.

Q. 26 With the help of a circuit diagram explain the use of n-p-n transistor as an amplifier in common emitter configuration. What is the phase relationship between collector and base voltages? 3

Ans. For common emitter amplifier see unit 12.

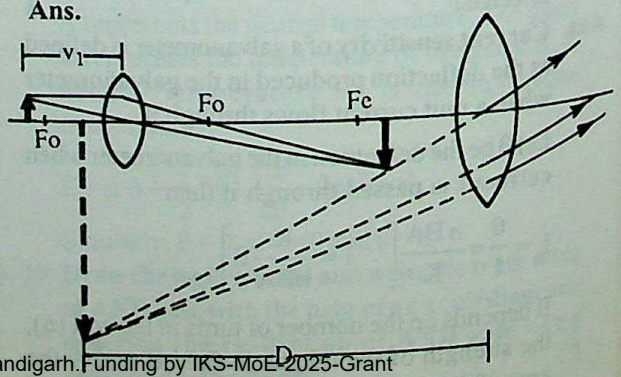
Once the collector voltage Vce exceeds the base voltage, the collector current is almost independent of the collector voltage.

Q. 27 You are given three lenses L_1, L_2 and L_3 having power P and aperture A as follows :

L_1 $P_1 = 6D$ $A_1 = 1$cm
L_2 $P_2 = 3D$ $A_2 = 8$ cm
L_3 $P_3 = 10D$ $A_3 = 1$ cm

Which of the two lenses would you use to construct a best possible (i) Telescope (ii) Microscope and why? 3

Ans.



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For Microscope, lateral magnification is given by

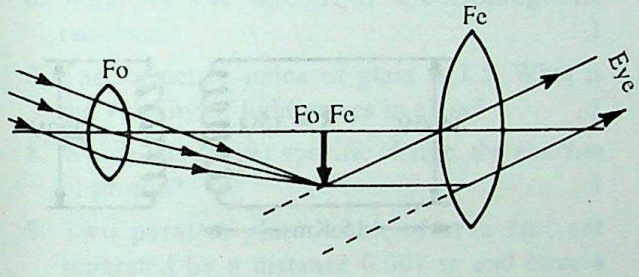
$$M=\left(\frac{D}{f_e}+1\right)\left(\frac{n_1}{f_0}-1\right)$$

For M to be large both fo and fe should be small Hence, P_1 == 6D & P_3 = 10D are two lenses suitable for microscope then L_1 and L_3 are to be used.

For a telescope objective has to be of large aperture.

$$M=\frac{f_o}{f_e} \qquad \text{here, } f_o >> f_e, \; P_o << P_e$$

Lenses to be used are L_2 and L_3, L_2 as objective and L_3 as an eye piece.



Astronomical Telescope

Q. 28 State postulates of Bohr's atomic model and derive an expression for the total energy of an electron in the nth orbit. 5

Ans. The postulates of Bohr's model are :

(1) Every atom consists of a central core called nucleus, in which entire positive charge and almost entire mass of the atom arc concentrated. A suitable number of electrons (having as much negative charge as the positive charge on the nucleus) revolve around the nucleus in the circular orbits. The centripetal force required for revolution is provided by the electrostatic force of attraction between the electron and the nucleus.

$$F=\frac{mv^2}{r}$$

$$\frac{1}{4\pi\epsilon_0}\frac{(Ze).(e)}{r^2}=\frac{KZe^2}{r^2} \quad \text{_____ (i)}$$

(2) According to Bohr, electron can revolve only in certain discrete non radiating orbits called stationary orbits, for which total angular momentum of the revolving electron is an integral multiple of $h/2\pi$ where h is a planck's constant.

$$mvr=\frac{nh}{2\pi} \qquad \text{___ (2)}$$

where n is any positive integer 1,2,3.

(3) The radiation of energy occurs only when an electron jumps from one permitted orbit to another. If E_1, is total energy of electron in the inner orbit and E_2 is its total energy in an outer orbit, then the frequency ν of radiation emitted on jumping from outer to inner orbits is given by

$$h\nu = E_2 - E_1$$

Total energy of electrons in the orbit :

$$E = K.E + P.E$$

$$\frac{1}{2}\frac{KZe^2}{r}-\frac{KZe^2}{r}=-\frac{KZe^2}{2r}$$

$$r=\frac{n^2h^2}{4\pi^2mKZe^2}$$

$$\therefore\ E=\frac{2\pi^2mK^2Z^2e^4}{n^2h^2}$$

Q. 29 State Gauss Theorem in electrostatic and use it to derive an expression for the electric field due to an isolated charged hollow sphere at a point. 5

(i) inside the sphere

(ii) outside the sphere.

Ans. Gauss's Theorem : The total electric flux through a closed surface is $\frac{1}{\epsilon_0}$ times the total charge enclosed inside the closed surface.

or

The surface integral of electrostatic field $\vec{E}$ produced by any sources over any closed surface S enclosing a volume V in vacuum Eo total electric flux over the closed surface S in vacuum is $1/\epsilon_0$ times the total charge (Q) contained inside S

$$\phi E = \oint \vec{E}\,\vec{ds} = \frac{Q}{\epsilon_0}.$$

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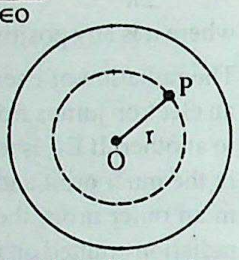
(i) **Electric field inside a hollow charged sphere :** Consider a point P inside a hollow charged sphere. Let E be the electric field at P. Draw an imaginary sphere of radius r and the point P lies on this Gaussian surface

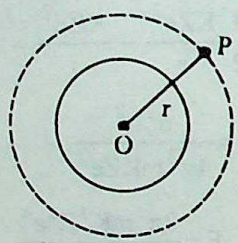
$$\therefore \oint E.ds = \frac{\Sigma q}{\epsilon o}$$



Here charge inside hollow sphere is zero

Hence, $E = 0$.

(ii) **Outside the sphere :** Here the point P lies outside, hence,



$$\oint Eds = \frac{\Sigma q}{\epsilon_0}$$

$$E \times 4\pi r^2 = \frac{q}{\epsilon_0} \quad \therefore E = \frac{q}{4\pi \epsilon_0 r^2}$$

OR

Derive an expression for the energy stored in a capacitor of capacitance 'C' when it is charged by connecting it to a battery of p.d.V. Now if the capacitor is disconnected from the battery, what will be the energy stored in the capacitor? When (i) separation between plates is doubled and (ii) an uncharged and identical capacitor is connected across it?

Ans. For energy of capacitor see unit 1 B.

(i) When separation is doubled

$Q = C'V' = CV$

$$\therefore V' = \frac{CV}{C'} = \frac{CV}{C/2} = \frac{2CV}{C} = 2V$$

The energy will become four times.

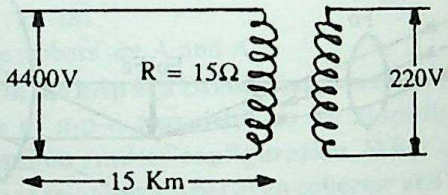
(ii) When an uncharged and identical capacitor is connected across it the capacity will be double but the potential is reduced to ½. Hence, the energy will be half of the original energy.

Q. 30 A small town with a demand of 880 kW of electric power at 220V is situated 15 km away from an electric plant generating power at 4400 V. The resistance of the cable carrying power is 15 ohm. The town gets power through a 4400 - 220 V step down transformer at a sub-station in the town.

(a) Calculate the line power loss in the form of heat.

(b) How much power must the plant supply assuming there is a negligible power loss due to leakage.

(c) Calculate the voltage drop in the line. 5



$$220 \times I' = 880 \times 10^3$$

$$I' = \frac{880}{220} \times 10^3 = 4 \times 10^3 \text{ A}$$

$$\frac{n_1}{n_2} = \frac{4400}{220} = 20$$

$$\therefore \quad I = \frac{4 \times 10^3}{20} \text{A} = 2 \times 10^2 \text{ A}$$

$$\text{Heat losses} = 4 \times 10^4 \times 15 \text{W}$$

$$= 60 \times 10^4 \text{ W}$$

$$= 600 \times 10^3$$

$$= 600 \text{ kW}$$

$$\text{Total power generated} = (880 + 600) \text{ kW}$$

$$= \mathbf{1480 \text{ kW}}.$$

$$\text{Voltage drop across the line} = 2 \times 10^2 \times 15 \text{ V}$$

$$= \mathbf{3000 \text{ V}}.$$

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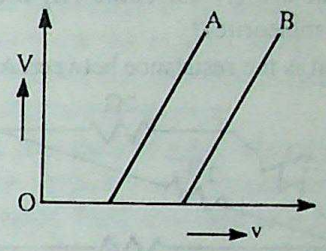
MODEL TEST PAPER — 1

Time 3 hours **Maximum Marks : 70**

General Instructions :

Same as in Sample Paper I

1. Draw lines of force due to two equal and opposite charges. 1
2. If the length of a wire is doubled and its area of cross-section is decreased to half, what happens to its resistance? 1
3. What is Peltier effect? Is it reversible? 1
4. Write the expression for B due to an infinitely long current carrying straight wire. 1
5. What is magnetic length? Is it the same as geometric length? 1
6. What is the speed of electromagnetic radiation? 1
7. The refractive index of glass is 1.5. What is the velocity of light waves in glass? 1
8. Which has greater specific charge, the electron or proton? 1
9. Two parallel plates each of area $1 m^2$ are separated by a distance 0.001 m and have a capacity of 0.1 μF. What must be the dielectric constant of the material separating the plates? 2
10. State Gauss's theorem in electrostatics. Apply this theorem to calculate the electric field inside a hollow conducting sphere. 2
11. What is Wheatstone's bridge? What is the condition for balance? 2
12. A transformer has 50 turns in one coil and 300 turns in the other. It is connected to a 240 V, A.C. power line. What is the voltage across the secondary? 2
13. In a spectrometer, for the prism A = 60°, calculate the angle of minimum deviation if μ of the prism for orange light is 1·647. 2
14. The graphs between the stopping potential V and frequency ν of the incident radiation on two different metal plates A and B are shown in the figure. Which metal out of A and B has the greater vlaue of the work function and why? 2



15. What are postulates of Bohr's theory of hydrogen atom? 2
16. Which type of biasing results in a very high resistance of a p-n junction diode? Draw a diagram showing this bias. 2
17. Two parallel plates carrying equal and opposite charge densities $+\sigma$ and $-\sigma$ $C\text{-}cm^{-3}$ respectively are held a certain distance apart. What is the nature of the electric field outside and between the plates? 2
18. A circuit contains a 10Ω resistor and 5μF capacitor in series with a 220 volt A.C. source of angular frequency 50 Hz. Calculate the impedance of the circuit. 2
19. Define electric dipole moment. Derive an expression for the electric field at any point along the equatorial line of an electric dipole. 3
20. What do you understand by a thermocouple and a thermopile? How can they be used for temperature measurement? 3
21. A circular coil is placed in a uniform magnetic field of strength 0.20 T normal to the plane of the coil. If the current in the coil is 2A, find
    (i) Total torque on the coil.
    (ii) Total force on the coil.
    (iii) Average force on each electron in the coil due to the magnetic field (the coil is made of copper wire of cross sectional area 10^{-5} m^2 and the electron density in copper is 10^{29} m^{-3}). 3
22. Derive an expression for the couple acting on a bar magnet placed at an angle θ with the direction

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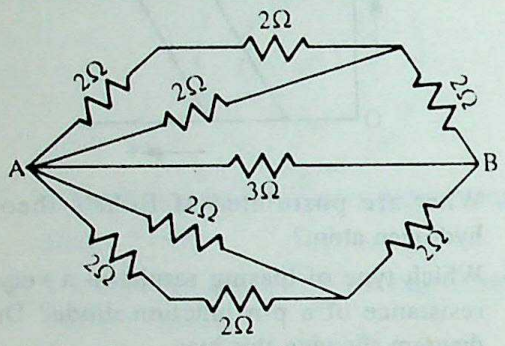
of a uniform magnetic field. When this couple is zero? 3

23. An alternating e.m.f is applied to a circuit containing an inductor coil. Find the relation between the e.m.f and the current in the circuit. Also, find the average power. 3
24. What are (i) asteroids (ii) meteoroids and (iii) meteorites? 3
25. What is the resistance between A and B? 3

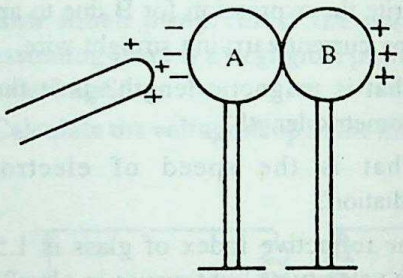


26. Derive Lens maker's formula. 3
27. Discuss the discovery of neutrons. Give their properties. 3
28. What is photoelectric effect? Explain laws of photoelectric emission. Give two applications of photoelectric cell. 5
29. Explain the term, 'sharpness of resonance'. Discuss how the sharpness of resonance varies with resistance in a series LCR circuit. What do you mean by quality factor of the circuit? 5

or

With the help of a labelled diagram explain the principle, construction and working of an a.c. generator. 5

30. A glass rod rubbed with silk is brought close to two uncharged spheres in contact with each other inducing charging on them as shown in figure. Show with diagrams in each case what happens when



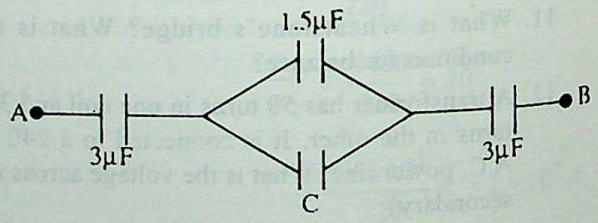
(i) The spheres are slightly separated.
(ii) The glass rod is subsequently removed.
(iii) The spheres are separated far apart. 5

MODEL TEST PAPER — 2

Time 3 hours **Maximum Marks 70**

General Instructions :
Same as in Sample Paper I

1. What is the difference between an e.m.f and potential difference? 1
2. Define electrochemical equivalent of a substance. 1
3. Do two parallel current carrying wires attract or repel each other? 1
4. Define one Henry. 1
5. Does electromagnetic radiation require any medium for propagation? 1
6. What is a wavefront? 1
7. What is critical frequency? Does it depend on the intensity of light? 1
8. What is one electron-volt? Express it in joule. 1
9. The equivalent capacitance of the network given below is 1 μF. What is the value of C? 2



10. What is the internal resistance of a cell? On what factors does it depend? 2
11. A tunning circuit in a radio transmitter has a 5×10^{-6} henry inductance in series with a 2×10^{-11} F capacitance. Find :
    (i) the frequency of the wave transmitted. 2
    (ii) their wavelengths. 2
12. State the characteristics of e.m. waves.

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13. Two lenses of powers + 4 and –2 dioptres respectively are placed 10 cm apart. What is the focal length and power of the combination? 2

14. A proton and an electron have same de Broglie wavelength. Which of them moves fast and which possesses more kinetic energy? Justify your answer. 2

15. What are chief merits of junction diodes over vacuum tube diodes? 2

16. Calculate the mutual potential energy between two protons when the distance between the two protons = 6×10^{-14} m and the charge on each proton = $1{\cdot}6 \times 10^{-19}$ C. 2

17. A given resistance has four colour bands - yellow, brown, red and silver. What is the value of the resistance? Also, give the tolerance. 2

18. A wire of resistance 4R is bent in the form of a circle. What is the effective resistance between the ends of diameter? 2

19. What is fission? What are the functions of moderator and control rods in a nuclear reactor? 3

20. What is Thomson effect? What do you understand by positive and negative Thomson effect? Is Thomson effect zero for any metal? 3

21. What is a Wheatstone bridge? Derive the condition for a balanced Wheatstone bridge. When the bridge will be most sensitive? 3

22. Derive an expression for the magnetic field at a point on the axis of a current carrying circular loop of wire. 3

23. Explain briefly how the mass of a star can be determined. 3

24. Outline Bohr's theory of hydrogen atom. Explain the origin of spectral lines of hydrogen using this theory. 3

25. An A. C. voltage $V = V_0 e^{iwt}$ is applied to a circuit having an inductance L, a capacitance C and a resistance R in series. Derive the expression for the current at any instant of time, Deduce the condition under which electrical resonance occurs.

26. What is dispersion of light? With the help of a diagram, expalin the construction of a spectrometer. How it is used to determine the refractive index of the material of the prism? 3

27. On the basis of the energy band diagrams, distinguish between :
(i) a metal
(ii) an insulator and
(iii) a semiconductor. 3

28. Explain with the help of a circuit diagram the working principle of a transistor as an amplifier in the common emitter configuration. Derive the expression for the voltage gain of the amplifier. 5

or

With the help of a labelled diagram, explain the construction and working of a Van de Graaff generator. Mention its uses. 5

29. Explain the formation of energy bands in solids. Distinguish between conductors, extrinsic and intrinsic semiconductors and insulators on the basis of band theory. 5

30. Describe Young's double slit experiment for producing interference of light. Obtain an expression for the fringe width 'w' in terms of the distance D of the observation plane from the double slit, the separation 'd' between the two slits and the wavelength λ of light 5

MODEL TEST PAPER — 3

Time 3 hours **Maximum Marks 70**

General Instructions : Same as in Sample Paper I .

1. What is meant by the principle of conservation of electric charge? 1

2. What is the resistance of an ideal voltmeter ? 1

3. For how long must a steady current of 1 A flow through a copper voltmeter to deposit 10^{-3} kg of copper ? Z for Cu is 0.000329 gC^{-1}. 1

4. State Ampere's law for the magnetic field produced by a straight current-carrying conductor. 1

5. When is the couple acting on a bar magnet,

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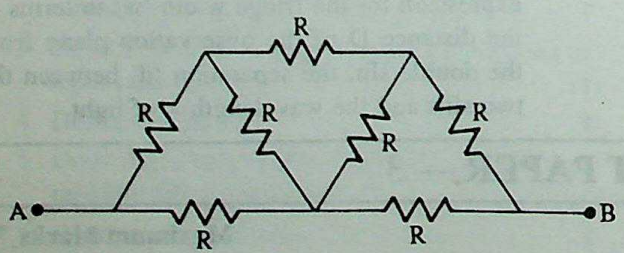
placed in a uniform magnetic field, zero? 1

6. Why a small ozone layer on top of the atmosphere is crucial for human survival? 1
7. What is polarization? Is sunlight polarized ? 1
8. What is electromagnetic induction? 1
9. Give logic symbol and truth table of a NAND gate. 2
10. An air capacitor with plates 1 m^2 area each and 0.01 metre apart is charged with 10^{-6} C of electricity. Calculate the change in energy which results when the capacitor is submerged in oil of relative permittivity 2.0. 2
11. State Kirchhoff's rules and explain them with the help of an example. 2
12. Prove that total energy stored in an inductor is $\frac{1}{2}LI_{max}^2$, where I_{max} is the maximum current through the inductor. 2
13. How are e.m. waves produced? 2
14. Name the colour that :
    (i) shows the maximum deviation
    (ii) shows the minimum deviation, through a prism. 2
15. An electron and proton have same kinetic energy. Which of the two has greater wavelength? Justify your answer. 2
16. Which has greater resistance – a forward biased p-n junction or a reverse-biased p-n junction? Draw diagrams showing the bias. 2
17. In the network shown below each resistance is 1Ω. What is the effective resistance between A and B? 2



18. Name different types of binding in crystal. Mention two characteristics of ionic binding. 2
19. Compare electrostatic force and gravitational force between an electron and proton placed at a certain distance apart in vacuum. 3
20. Derive an expression for the total work done in rotating the electric dipole through an angle θ in uniform electric field E. 3
21. How a thermocouple is used for measuring the temperature? What are the advantages of a thermocouple used as a temperature measuring device? 3
22. What is an ammeter? How can a galvanometer. be converted into an ammeter? Explain with circuit diagram. 3
23. Explain the principle of tangent galvanometer. Derive the relation between current and the angle of deflection. 3
24. Define unit magnetic pole in S.I. unit. Give the formula for the intensity of the magnetic field at any point on the axial line. 3
25. How do we estimate planetary distances and sizes? Give the relevant theory. 3
26. Deduce the laws of refraction on the basis of Huygen's principle. 3
27. For two thin lenses of focal lengths f_1 and f_2 obtain an expression for the equivalent focal length F; when the two lenses are :
    (i) in contact, and
    (ii) separated by a distance d. 3
28. Giving a labelled diagram, describe Millikan's method for the determination of charge on an electron. Also, give the principle of the method. 5
29. Describe the principle and construction of a moving coil galvanometer. Prove that the current flowing in the coil is directly proportional to its deflection. What is the importance of a radial fields? 5

or

Distinguish between self-inductance and mutual inductance. Calculate the self inductance of a long solenoid coil of length *l*, number of turns N and radius r. Define henry. 5

30. What is a p-n junction diode? Define the term dynamic resistance of the junction diode. With the help of a circuit diagram, explain the working of p-n junction diode as a full wave rectifier. 5

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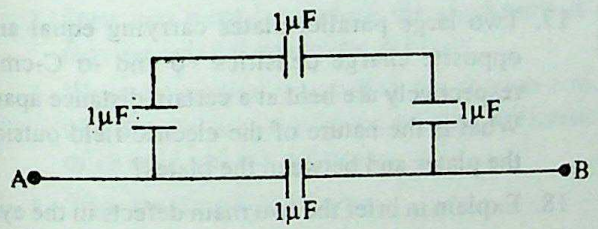
MODEL TEST PAPER — 4

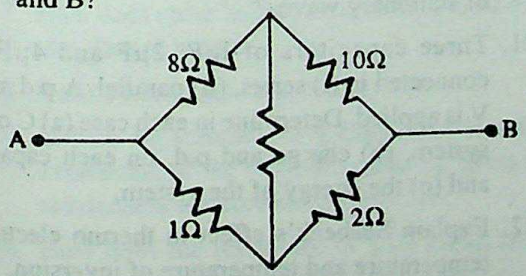
Time 3 hours **Maximum Marks 70**

General Instructions : Same as in Sample Paper I

1. Give mathematical relation between electrostatic potential and field. 1
2. What is Seebeck's effect? 1
3. Write the expression for magnetic field (B) at the centre of a current - carrying circular loop. 1
4. What is the wattless current? 1
5. Draw the intensity distribution graph for Young's doublé slit experiment. 1
6. What is the energy equivalent to 1 gm of mass? 1
7. What is work done by the field of a nucleus in a complete circular orbit of electron? 1
8. Define one lumen. 1
9. Give the logic symbol and truth table of a NOT gate. 2
10. What is the effective capacitance between A and B in the following figure? 2



11. Find the energy stored in a capacitor of capacitance C, charged to a p.d. of V and having a charge Q. 2
12. What is the equivalent resistance between A and B? 2



13. A sinusoidal e.m.f is applied to a circuit containing a capacitor only. Show that current leads the voltage by $\frac{\pi}{2}$. 2
14. What is earth's atmosphere? How it is classified into different layers? 2
15. Define resolving power of an optical instrument. How it depends on wavelength? 2
16. An electron moving with a speed of 2.5×10^{-7} ms^{-1} is deflected by an electric field of 1600 Vm^{-1} perpendicular to its path. If the radius of the electron trajectory is 2·3 m, calculate e/m for the electron. 2
17. Distinguish between nuclear fission and nuclear fusion. 2
18. Define current amplification factors α and β respectively of a common base transistor and common emitter transistor. How are α and β related to each other? 2
19. Two electric bulbs of 50 and 100 watts are connected in (i) series and then (ii) parallel. In which case the intensity of light will be brighter? 3
20. What are polaroids? Give their uses. 3
21. What is a solar cell? How it works? Give its two uses. 3
22. Obtain an expression for the intensity of the electric field at a point on the axis of a uniformly charged circular ring of radius 'a' at a distance 'x' from its centre. 3
23. Describe the working of a secondary cell. 3
24. What is a voltmeter? How a galvanometer can be converted into a voltmeter? Explain with circuit diagram. 3
25. Derive an expression for the magnetic field on the axis of a toroidal solenoid. What is the charge in magnetic field inside a solenoid carrying a current if the length of the solenoid is doubled and the no. of turns remain the same? 3
26. State Coulomb's law for magnetic poles. Derive an expression for the moment of a couple in a uniform magnetic field. 3
27. What is meant by the black body temperature? How do we use the Wien's displacement law and the Stefan's law in estimating the surface temperature of a star? 3
28. Describe the principle, construction and working of a transformer. Why is the core of a transformer laminated? 5

or

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Giving a labelled diagram, describe the principle and the method for determining of e/m of electrons by Thomson's method. 5

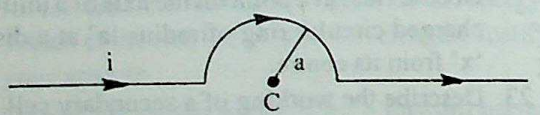
29. Explain how an intrinsic semiconductor can be converted into :
    (i) n-type and
    (ii) p-type semiconductor.
    Give one example of each and their energy band diagrams. 5
30. Describe an astronomical telescope. Derive expression for its magnifying power when final image is :
    (i) at infinity
    (ii) at least distance of distinct vision. 5

MODEL TEST PAPER — 5

Time 3 hours **Maximum Marks 70**

General Instructions : Same as in Sample Paper-I.

1. Under what conditions does the potential difference across the terminals of a battery equal its e.m.f.? 1
2. Three equal resistors connected in series with a battery, together dissipate 10 W of power. What will be the power dissipated if the same resistances are connected in parallel across the same battery? 1
3. A current I flows through a wire as shown in the figure. What is the magnetic field at C, the centre of the semi circle, due to semi circle of radius a? 1



4. Define magnetic lines of force. Depict the magnetic lines of force due to a bar magnet. 1
5. Why can't a transformer be used to step up d.c. voltage? 1
6. Why sky wave propagation of e.m. waves can not be used for TV transmission? 1
7. What is red shift? 1
8. What is a chain reaction? How is it sustained? 1
9. State Coulomb's law of force between a pair of electric charges. In what way does it resemble and differ from the gravitational law? 2
10. Using the concept of drift velocity, derive Ohm's law. 2
11. A sinusoidal e.m.f is applied to a circuit containing an inductor only. Show that current lags behind the voltage by $\pi/2$. 2
12. Explain green house effect. 2
13. Explain the formation of mirage in deserts. 2
14. The voltage across the electrodes of a cathode ray gun is 500 V. Calculate (i) the energy gained by the electrons, (ii) the speed of the electrons. 2
15. Explain the difference between mean life and half life of a radioactive sample. 2
16. Draw a labelled voltage - current curve for a junction diode and explain briefly. 2
17. Two large parallel plates carrying equal and opposite charge densities $+\phi$ and $-\sigma$ C-cm^{-3} respectively are held at a certain distance apart. What is the nature of the electric field outside the plates and between the plates? 2
18. Explain in brief the two main defects in the eye. 2
19. How cathode rays are produced? Give their two properties. 3
20. What are the necessary conditions for production of stationary waves? 3
21. Three capacitors of 1μF, 2μF and 4μF are connected in (i) series, (ii) parallel. A p.d. of 50 V is applied. Determine in each case (a) C of the system, (b) charge and p.d. on each capacitor and (c) the energy of the system. 3
22. Explain Seebeck's effect in thermo electricity temperature and temperature of inversion. 3
23. State the principle of a potentiometer. How will you find the internal resistance of a cell using it? 3
24. Describe with the help of a labelled diagram the construction of a moving coil galvanometer. Derive the formula connecting the current and deflection produced. 3

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25. Describe a deflection magnetometer. How would you use it to compare magnetic moments of two short bar magnets? 3

26. How is the brightness magnitude scale of stars defined? Show that the ratio of brightness of two stars of magnitude n_1 and n_2 is $(100)^{\frac{(n_2 - n_1)}{5}}$. 3

27. What is meant by dispersion of light? Derive an expression for the refractive index of the material of a prism in terms of angle of prism and angle of minimum deviation. 3

28. A circuit contains an inductance and a resistance. If it is subjected to an alternating e.m.f, determine the current in the circuit. Also, calculate the impedance and phase lag in the circuit. 5

29. Explain with the help of a labelled circuit diagram how a common emitter n-p-n transistor can be used as an amplifier. Derive an expression for its voltage gain. 5

OR

State Bohr's postulates regarding the structure of the hydrogen atom and derive the expression for the energy of the atom in its nth stationary state. 5

30. Discuss common emitter amplifier, using n-p-n transistor. Find its current gain, voltage gain and power gain. 5

MODEL TEST PAPER — 6

Time 3 hours **Maximum Marks 70**

General Instructions : Same as in Sample Paper I

1. What is meant by quantization of electric charge? 1

2. State two factors on which the sensitivity of a moving coil galvanometer depends. 1

3. Write expression connecting the thermo e.m.f of a thermo couple with temperature difference of its cold and hot junctions. 1

4. State the Biot-Savart's law. 1

5. State Gauss's theorem. 1

6. Which device will you use to step-up a.c. voltage? Can we use the same device to step-up d.c. voltage? 1

7. How does radar help in determining the distance of a distant object? 1

8. Define luminous flux. Name its unit. 1

9. Define capacitance of a capacitor. Derive an expression of the resultant capacity when three condensers are connected in series. 2

10. How does the resistance of a (i) metal and (ii) semiconductor, vary with temperature? 2

11 Define r.m.s value of a.c. What is the average value of a.c. during a (i) half cycle and (ii) full cycle? 2

12. Explain the terms (i) ground wave and (ii) sky wave. 2

13. What is magnifying power for a visual optical instrument? Define it for a microscope. 2

14. When an electron jumps across a potential difference V volts, show that the de Broglie, wavelength is given by $\lambda = \frac{12{\cdot}3\,\text{Å}}{\sqrt{V}}$. 2

15. Will neutron to proton ratio increase or decrease, when a radioactive nucleus emits (i) an alpha particle (ii) a beta particle? Give one example in each case in support of your answer. 2

16. Give logic symbol, truth table and circuit diagram of an AND gate. 2

17. A given resistance has the following colour bands: yellow, violet, brown and gold. What is the value of the resistance? Also give its tolerance. 2

18. Define electrostatic potential at a point. Calculate electrostatic potential at a distance of 10 cm from a point charge of 1 μC. 2

19. What is a transformer? What is its principle? 3

20. What is total internal reflection? What are its conditions? 3

21. Prove that net force acting on a electric dipole, oriented at an angle θ to a uniform electric field E, is zero. Draw a diagram. 3

22. Define the term electrochemical equivalent. A copper voltmeter and an ammeter are connected in series with a battery through a resistance. In one hour 1 gm copper is deposited on the plates.

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The ammeter reads 0.9 A. Calculate the error in its reading. e.c.e. of copper is 0.00032 gmC^{-1}. 3

23. What is an e.m.f of a cell? How a potentiometer can be used to compare the e.m.f of two cells? Explain. 3
24. Derive an expression for the magnetic field at the centre of a circular coil of radius r carrying current I ampere. What is the magnetic force acting on a closed loop carrying a current placed in a uniform magnetic field B? 3
25. Define and explain the elements of earth's magnetic field at a place. 3
26. Explain the mechanism of energy production in stars. 3
27. What is Brewster's law? What will be refractive index of a transparent medium with a polarising angle of 60°? 3
28. What is a p-n junction? How is p-n junction made? Describe how it is used as a half wave rectifier and define the dynamic resistance of a junction diode. 5
29. State the basic postulates of Bohr's theory of atomic spectra. Hence, obtain an expression for the energy of orbital electron in hydrogen atom. Draw the energy level diagram of hydrogen spectrum. 5

OR

Establish Einstein photo-electric relation. Explain the laws of photoelectric emission on the basis of this relation. Find the relation between cut off potential frequency of the incident light and threshold frequency. What is photocell? 5

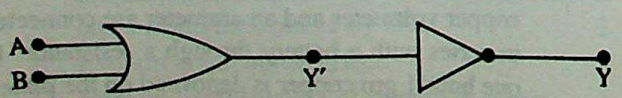
30. What is potentiometer? Explain its principle and working. How can you compare the e.m.f of two cells using potentiometer? 5

MODEL TEST PAPER — 7

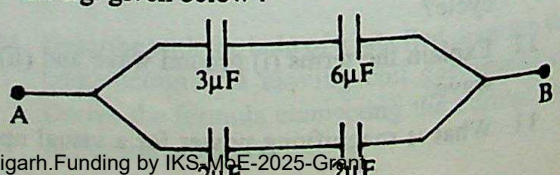
Time 3 hours **Maximum Marks 70**

General Instructions : Same as in Sample Paper 1

1. Suggest a method to produce a uniform electric field in a region of space. 1
2. Define Thomson coefficient. 1
3. Write down the expression for the force acting on a charge that moves in a magnetic field. 1
4. Do we require a.c. or d.c. for long distance transmission? 1
5. Why are short waves used in long distance broadcasts? 1
6. How do wavelength and frequency of light change when it goes from vacuum into medium? 1
6. Why does a setting or a rising sun appear reddish? 1
8. The luminous flux of a 60 watt bulb is 600 lumen. What is the luminous efficiency of the bulb? 1
9. Derive an expression for the energy stored in a capacitor. 2
10. Identify the logic gate and give its truth table. 2



11. How do we connect a galvanometer, an ammeter and a voltmeter in a circuit? 2
12. Show that the average power dissipated per cycle in an LCR circuit is given by $P = V_{eff} I_{eff} \cos\phi$, where ϕ is the angle of lag or lead. 2
13. A TV tower has height of h metre. Determine the area of earth's surface over which the programmes from the tower can be received. 2
14. Draw a ray diagram of a compound microscope. What is the nature of the image formed? 2
15. What is the energy of emitted photoelectrons if light of frequency 1×10^5 Hz is incident on a sodium target? Work function of sodium = 2·5 eV. 2
16. Give the logic symbol, truth table, Boolean expression and realization (circuit diagram) of an OR gate. 2
17. Calculate the capacitance between A and B in the fig. given below : 2



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18. What are thermal neutrons? Why are neutrons considered as ideal particles for nuclear fission? 2

19. State Gauss's theorem and apply this theorem to calculate the electric field inside a hollow conducting sphere. 3

20. State Huygen's principle. Prove Snell's law by using this principle. 3

21. What is rectification? With the help of a labelled circuit diagram, explain full wave rectification using junction diodes. 3

22. Give an experiment to prove transverse nature of light. 3

23. A current is flowing through a straight thin long metallic conductor. Obtain an expression for magnetic field at a distance 'd' from it. What will be field for infinitely long conductor? 3

24. What is diffraction of light? How does it differ from interference of light? 3

25. Describe the charging process of a capacitor through a resistor. Explain the variation of the charge on the capacitor and current through the circuit. What is the time constant of the circuit? 3

26. With a proper circuit diagram, show the biasing of a NPN transistor. Explain the movement of charge carriers through different parts of a transistor. Hence, show that $I_A = I_B + I_C$ 3

27. A wire of resistance 10 Ω is drawn out so that its length is increased to twice its original length. Calculate its new resistance. 3

28. With the help of a labelled diagram explain the principle construction and working of a step up transformer. Why is the core laminated? 5

OR

A coil of inductance 0.50 H and resistance 100 r is connected to an a.c. supply of 240 V (50 Hz). Calculate the current in the coil and also calculate the time lag between voltage and current. 5

29. State Gauss's theorem in electrostatics and use it to derive an expression for electric field due to an isolated charged hollow sphere : (i) Inside the sphere. (ii) Outside the sphere. 5

30. Define the terms electric dipole and dipole moment. Derive an expression for the electric field intensity at a point on equatorial line of a dipole. 5

MODEL TEST PAPER—8

Maximum Marks 70

Time 3 hours

General Instructions : Same as in Sample Paper I

1. What is the difference between a magnetic dipole and an electric dipole? 1

2. Define resistivity of a conductor and how does it vary with temperature. 1

3. Mention some applications of thermo-electricity. 1

4. What is magnetic dipole moment? Is it scalar or vector? 1

5. What is the principle of a vibration magneto-meter? 1

6. What is the coefficient of mutual inductance of two coils? 1

7. What is rainbow? How is it formed? 1

8. On what factors the focal length of a lens depends? 1

9. Derive an expression for electric field at a point due to a uniformly charged sphere, using Gauss's law. 2

10. What is a potentiometer? State its working principle. 2

11. An electric lamp, which runs at 80 V d.c. and consumes 10 A, is connected to a 100 V, 50 Hz a.c. mains. Calculate the inductance of the choke required. 2

12. Which part of the earth's atmosphere contains ozone layer? What is its importance? 2

13. The wavelength of a spectral line is 5000 Å. Calculate its frequency and energy. Given velocity of light = 3×10^8 ms^{-1}, $h = 6.6 \times 10^{-34}$ Js. 2

14. What is semiconductor? Why it is doped? What are different dopents used to get impurity semiconductors? 2

15. n cells each of e.m.f 'E' and internal resistance 'r' are connected in parallel to an external resistance R. Obtain the expression of current flowing through the circuit. 2

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16. A 100 V, 50 Hz a.c. source is connected to a series combination of an induction coil of 100 m henry and a resistance of 25Ω. Calculate the magnitude and phase of the current. 2
17. Define : (i) Luminous flux, (ii) Luminous intensity and (iii) Illuminance. 2
18. Prove that $\mu = \frac{1}{\text{Sin C}}$, where C is the critical angle. 2
19. Explain the Einstein's interpretation of phenomenon of photoelectricity. 3
20. Define Seebeck's coefficient and Peltier's coefficient? Write the relationship between them. 3
21. Establish the relation between current and drift velocity. Deduce the expression for resistivity. 3
22. Define the unit of current 'Ampere' by considering the passage of electric current through two straight parallel conductors of negligible cross section. What is the magnetic field at the centre of a circular coil having 10 turns of diameter 20 cm. and carrying a current of one ampere? 3
23. Define neutral points. Locate the position of neutral points when a small bar magnet is placed with its north pole (i) towards north of the earth and (ii) towards south of the earth. 3
24. Give Young's double slit experiment on interference of light, obtain an expression for the fringe width β. 3
25. What is a parallel plate capacitor? Derive the expression for capacitance of parallel plate capacitor with medium : (i) vacuum and (ii) vacuum and dicelctric plate between the plates. 3
26. What is self induction? Define self inductance and calculate its value for a long solenoid of length L, no. of turns N and radius r. 3
27. What is the difference between a nuclear fission and fusion? Explain the term chain reaction. What are the functions of moderator and control rods in a nuclear reactor? 3
28. Explain with the help of a labelled circuit diagram the use of an n-p-n transistor as an amplifier in common emitter configuration. Obtain an expression for its voltage gain. 5

OR

Explain the formation of energy bands in solids, and hence, define conduction band and valence band. Distinguish between semiconductors and insulators on the basis of their energy bands. 5
29. Define total internal reflection. State its conditions. Give any three applications of total internal reflection, why a tank of water appears shallow? 5
30. Give the brief history of electromagnetic waves. With the help of a schematic diagram explain Hertz's experimental set up for the production electromagnetic waves. What important conclusion was drawn from this experiment. 5

MODEL TEST PAPER — 9

Time 3 hours **Maximum Marks 70**

General Instructions : Same as in Sample Paper-I

1. State the law which incorporate both Coulomb's law of electrostatics and superposition principle. 1
2. Define temperature coefficient of electrical resistance. 1
3. The thermo e.m.f E (in volt) of a certain thermocouple is found to vary with θ (in °C) in accordance with the relation $E = 4\theta - \theta^2/10$, where θ is the temperature of the hot junction, the cold junction being kept at 0 °C. What is the neutral temperature of the couple? 1
4. What is the principle of a cyclotron? 1
5. Define time constant of an inductor-resistor circuit. 1
6. What is the fundamental source of e.m. radiation? 1
7. Which colour of light travels with maximum speed in glass? 1
8. What is the order of current in a transistor? 1
9. What is the equivalent resistance between A and B of the following circuit? 2

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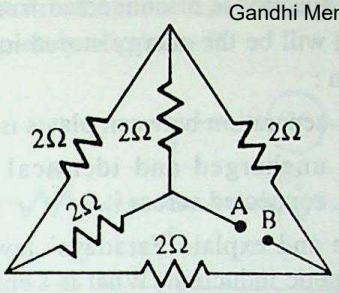

10. A 100 μF capacitor in series with a 40W resistance is connected to a 110 V, 60 Hz supply.
    (i) What is the maximum current in the circuit?
    (ii) What is the time lag between current maximum and voltage maximum? 2

11. A TV transmission tower has a height of 160 m.
    (i) What is the coverage range?
    (ii) How much population is covered if the average density around the tower is 1200 km^{-2}? 2

12. Name the colour having the :
    (i) minimum speed, and
    (ii) maximum speed, through a prism. 2

13. Distinguish between n-type and p-type semiconductors. 2

14. The total energy of an electron in the first excited state of the hydrogen atom is -3.4 eV. What is the (i) kinetic energy, (ii) potential energy of the electron in the state? 2

15. A parallel plate capacitor consists of two plates of area 10^{-2} sq. meter each separated by a distance of 0.01 m. A square glass slab of thickness 0.01 m and side 0.05 m is placed between the plates. Find the capacity of the capacitor. The dielectric constant of glass is 10. 2

16. An object 10 mm high is placed 0.3 m in front of a convex mirror of focal length 0.2 m so that it is perpendicular to, and has one end resting on the axis of the mirror. Find the length and position of the image formed by the mirror. 2

17. What is the difference between an intrinsic and an extrinsic semiconductors? 2

18. Differentiate between potential and potential energy. Two conducting spheres of radii R_1 and R_2 are connected by a long thin wire. They are charged to a common potential. Find the ratio of their charge densities. 2

19. Draw a labelled diagram of a Daniel cell. Write the necessary chemical reactions responsible for generating a potential difference between its electrodes. How is the defect of polarisation removed in this cell? 3

20. A galvanometer of resistance 10 Ω gives full scale deflection for a current of 2 mA. Calculate the shunt resistance required to convert it into an ammeter of range 0-5A. 3

21. State Ampere's law. What is the force on a conductor of length *l* carrying a current I when it is situated in a magnetic field of induction B? When is this force maximum? 3

22. Write down the expression for the torque experienced by a magnetic dipole in a uniform magnetic field. Hence, derive the expression for the potential energy of the dipole. 3

23. Show that when two masses M_1 and M_2 revolve about a common point with a period T, the sum of their masses is given by

$$M_1 + M_2 = \frac{4\pi^2}{G}(a^3 / T^2),$$

where *a* is the separation between the two masses. How is this relation used to estimate the mass of the earth from observations made on the moon? 3

24. State Huygen's principle of secondary wavelets. On the basis of this, obtain the laws of reflection. 3

25. Describe with the help of a labelled diagram the construction of a moving coil galvanometer. Derive the formula connecting the current and the deflection produced. 3

26. State the principle of an oscillator. Explain how a transistor can be used as an oscillator. 3

27. Distinguish between dia-, para-, and ferromagnetic materials. Also give examples. 3

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28. What do you mean by mutual induction and co-efficient of mutual induction? Find out the mutual inductance of two long solenoids. Two coils have mutual inductance of 1.5 henry. If the current in the primary circuit is raised to 5 ampere in one milli second after closing the circuit. What is the e.m.f induced in the secondary? 5

29. Derive an expression for the energy stored in a capacitor of capacitance C. When it is charged by connecting it to a battery of p.d. V. Now if the capacitor is disconnected from the battery, what will be the energy stored in the capacitor when :
    (i) separation between plates is doubled and
    (ii) uncharged and identical capacitor is connected across it. 5

30. State and explain Faradays' laws of electro-magnetic induction. What is Lenz's law? How will you verify it experimentally? Does it obey the principle of energy conservation? 5

MODEL TEST PAPER — 10

Time 3 hours **Maximum Marks 70**

General Instructions : Same as in Sample Paper I

1. Why two electric lines of force do not intersect? 1
2. State the conditions under which Ohm's law does not hold good. 1
3. Give the direction of thermoelectric current at the hot junction of iron-copper thermocouple. 1
4. State the principle of a tangent galvanometer. 1
5. What are eddy current? 1
6. If the earth did not have an atmosphere, would its average temperature be higher or lower than what it is now? 1
7. Why does sky appear blue? 1
8. What is the Big-Bang theory? 1
9. Derive an expression for the electric potential at a distance r from a point charge Q. 2
10. A battery supplies a current 0.9 A through a 2 Ω resistor and a current of 0.3 A through a 7Ω. resistor. What is the internal resistance of the battery? 2
11. A coil of area 0.15 m^2 and 100 turns is perpendicular to a magnetic field, which changes from 5×10^{-3} to 2×10^{-3} Wb m^{-2} in 30 ms, calculate the induced e.m.f. 2
12. Write Maxwell's equations and give the names associated with some of the four equations. 2
13. A lamp placed 50 cm from a screen on one side produces the same illumination as a standard 50 cd lamp placed 100 cm away on the other side, of the screen. What is the luminous intensity of the first lamp? 2
14. What is dispersion? How is it caused? Differentiate between line and continuous emission spectra. 2
15. Describe how a p-n junction can be used as a half-wave rectifier. 2
16. A wire of resistance 10Ω is drawn out so that its new length is double its original. Find the resistance of the longer wire, assuming the resistivity and density of material are unchanged during drawing process. 2
17. Name the different types of bonds in solids. What type of a bond is formed in (i) diamond and (ii) silicon? 2
18. What is nuclear fission? Why is heavy water used in a nuclear reactor? 2
19. The photoelectric work function for Na surface is 20 volt. Calculate the longest wavelength of light that will eject photoelectrons from Na surface. 3
20. What is the power of a lens? Two lenses of powers +5 D and –2 D are placed in contact, what is the power of combination? 3
21. Draw a labelled diagram of a Leclanche cell. How the problem of polarisation is overcome in this cell? 3
22. A voltmeter is connected across a resistance R_2 in the diagram. Calculate the error in the

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voltmeter reading. For what value of R_2 the error is completely eliminated? 3

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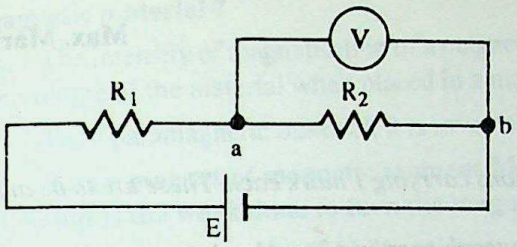

23. A current carrying wire loop is placed in a uniform magnetic field. Under what circumstances will there be : (a) No torque on the loop. (b) No net force? It is required to produce a magnetic field of magnitude 0·1 T inside a solenoid. How many turns per unit length are required if the current is 5A? 3

24. What is magnetic flux? Give its dimensions. Differentiate between magnetic field H and magnetic flux density B. Find an expression for the magnetic field due to a bar magnet at a point in the broad on position. 3

25. Name the nine planets. Distinguish between a planet and a star. 3

26. Give Lloyd's single mirror experiment on interference of light. What is the nature of the central fringe? 3

27. The photoelectric threshold wavelength of a metal is 10,000 Å, when light of wavelength 5461 Å is incident on it, retarding potential in Millikan's experiment is 1.02 eV. Calculate the value of Planck's constant. 3

28. With the help of a labelled diagram, explain the principle, construction and working of a step-down transformer? Can it be used with d.c.? 5

29. Give the principle of a cyclotron. Draw a labelled diagram of a cyclotron and explain how a positively charged particle is accelerated in it? 5

30. Write the construction of a p–n–p transistor. How it is symbolically represented? Explain its working. What type of emitter base and collector base biasing is needed for the use of transistor as a common base amplifier? 5

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PHYSICS (THEORY)

C.B.S.E. CLASS XII (SET I) — 2001 (DELHI BOARD)

Time allowed : 3 hours **Max. Marks : 70**

General Instructions :

(i) All questions are compulsory.
(ii) Marks for each question are indicated against it.
(iii) Question numbers 1 to 8 are very short- answer questions carrying 1 mark each. These are to be answered in one or two sentences.
(iv) Question numbers 9 to 18 are short-answer questions, each carrying 2 marks. Answer to these questions should be around 30 words each.
(v) Question numbers 19 to 27 are also short-answer questions, each carrying 3 marks. Answer to these questions should be around 50 words each.
(vi) Question numbers 28 to 30 are long-answer questions, each carrying 5 marks. Answer to these questions should be around 150 words each.
(vii) Use Log tables, if necessary.

Q. 1. Give two factors by which voltage sensitivity of a moving coil galvanometer can be increased. (1)

Ans. (i) By increasing the magnetic field strength of the magnet.

(ii) By increasing the number of turns of the galvanometer coil.

Q. 2. How does the maximum kinetic energy of electrons emitted vary with the work function of the metal ? (1)

Ans. The maximum kinetic energy of emitted electrons decreases with the increase in the work function.

Q. 3. How does the frequency of a beam of ultraviolet light change when it goes from air into glass ? (1)

Ans. It remains unchanged.

Q. 4. How does the luminosity of a star related to its surface temperature ? (1)

Ans. Luminosity of a star, $L \propto T^4$, where T is the surface temperature.

Q. 5. Why is heavy water used as moderator in a nuclear reactor ? (1)

Ans. Heavy water is used because, in collision with its molecules, neutrons lose their energy and get slowed down. Finally they become suitable for fission reaction.

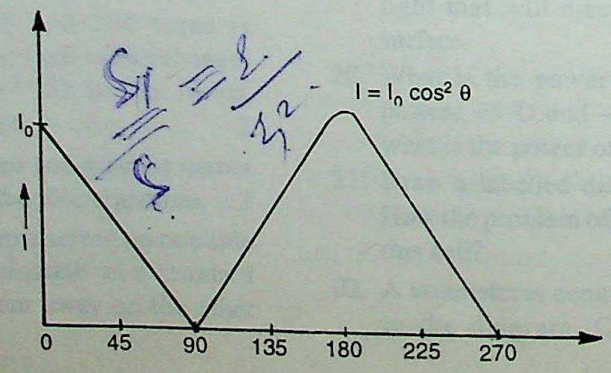
Q. 6. What is the power dissipation in an a.c. circuit in which voltage and current are given by

$$V = 300 \sin\left(\omega t - \frac{\pi}{2}\right) \text{ and } I = 5 \sin \omega t \text{ ?}$$ (1)

Ans. Power dissipation is zero, since the phase difference between voltage and current is $\pi/2$.

Q. 7. Draw the graph showing the variation of intensity of polarised light transmitted by an analyser. (1)

Ans.



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Q. 8. Give two defects of a voltaic cell. (1)

Ans. The main two defects are (i) polarisation (ii) local action.

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Q. 9. Define intensity of magnetisation of a magnetic material. How does it vary with temperature for a paramagnetic material ? (2)

Ans. The intensity of magnetisation of a magnetic material may be defined as the magnetic moment developed per unit volume of the material when placed in a magnetising field.

For a paramagnetic material, it is inversely proportional to the temperature.

Q. 10. A bar magnet of magnetic moment M is aligned parallel to the direction of a uniform magnetic field B. What is the work done to turn the magnet, so as to align its magnetic moment :

(i) opposite to the field direction and

(ii) normal to the field direction ? (2)

Ans. We have $W = -MB\cos(\theta_2 - \theta_1)$

(i) Here $\theta_1 = 0°$, $\theta_2 = 180°$.

$\therefore\ W = -MB(\cos 180° - \cos 0°) = -MB(-1-1) = 2MB$

(ii) Here $\theta_1 = 0°$, $\theta_2 = 90°$.

$\therefore\ W = -MB(\cos 90° - \cos 0°) = -MB(0-1) = MB$

Q. 11. Calculate the solar constant on a planet which is approximately 5 A.U. from the sun. Assume the solar constant on earth is 1400 W/m². (2)

Ans. Here, solar constant at earth, $S = 1400\ W/m^2$

Distance of earth from the sun, $r = 1$ A.U.

Distance of jupiter from the sun, $r_1 = 5$ A.U.

Let S_1 be the solar constant at jupiter then, using inverse square law,

$$\frac{S_1}{S} = \frac{r^2}{r_1^2} \quad \Rightarrow \quad \frac{S_1}{1400} = \frac{1}{25}$$

$$\Rightarrow S_1 = \frac{1400}{25} = 56\ W/m^2$$

Q. 12. Red light is incident on a thin converging lens of focal length *f*. Briefly explain, how the focal length of the lens will change if red light is replaced with blue light. (2)

Ans. We know that, $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$.

Here, R_1, R_2 are constant and only μ vary for different colours.

Also, $\mu_B > \mu_R$

$\therefore\ \frac{1}{f_B} > \frac{1}{f_R}$ or $f_B < f_R$.

Or the focal length will decrease.

Q. 13. The thermo e.m.f. of a thermo couple is given by the expression $E = \alpha\theta - \beta\theta^2$, where θ is the temperature of the hot junction. If $\alpha = 42\ \mu V\ °C^{-1}$ and $\beta = 0{\cdot}035\ \mu V\ °C^{-2}$, calculate the (i) neutral temperature, (ii) temperature of inversion of the thermo couple, if the cold junction is at 20 °C. (2)

Ans. We have $E = \alpha\theta - \beta\theta^2$

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$$\Rightarrow \frac{dE}{d\theta} = \alpha - 2\beta\theta$$

(i) At neutral temperature θ_n, $\frac{dE}{d\theta} = 0$

$$\Rightarrow \quad \alpha - 2\beta\theta_n = 0 \quad \Rightarrow \quad \theta_n = \frac{\alpha}{2\beta}$$

$$= \frac{42}{2 \times 0{\cdot}035} = \mathbf{600\ °C.}$$

(ii) We have $\theta_n = \frac{\theta_i + \theta_0}{2}$

$$\Rightarrow \quad 2\theta_n = \theta_i + \theta_0$$

$$\Rightarrow \quad \theta_i = 2\theta_n - \theta_0 = 1200 - 20 = \mathbf{1180\ °C.}$$

Q. 14. Sky waves are not used in transmitting T.V. signals. Why ? State two factors by which the range of transmission of T.V. signals can be increased. (2)

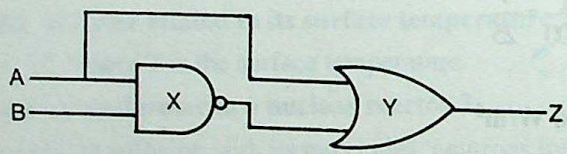
Ans. T.V. signal waves have the frequency range 100 MHz to 200 MHz. These waves neither follow the curvature of earth nor get reflected by ionosphere. Therefore, their communication via sky wave is not possible.

Range of T.V. signal can be increased by :

(i) using communication geostationary satellite.

(ii) using tall receiver antenna.

Q. 15. Identify the logic gates marked X, Y in the following figure. Write down the output at Z, when A = 1, B = 1 and A = 0, B = 1. (2)



Ans. X — NAND gate

Y — OR gate

Inputs		Output of NAND gate	Output of OR gate
A	B	$Y = \overline{A \cdot B}$	$Z = A + Y$
1	1	0	1
0	1	1	0

Q. 16. Calculate the current drawn by the primary of a transformer, which steps down 200 V to 20 V, to operate a device of resistance 20 Ω. Assume the efficiency of the transformer to be 80%. (2)

Ans. $I_2 = ?$, $I_1 = ?$, $R = 20\ \Omega$, $V_1 = 200\ V$, $V_2 = 20\ V$.

Current in secondary, $I_2 = \frac{V_2}{R} = \frac{20}{20} = 1\ A$

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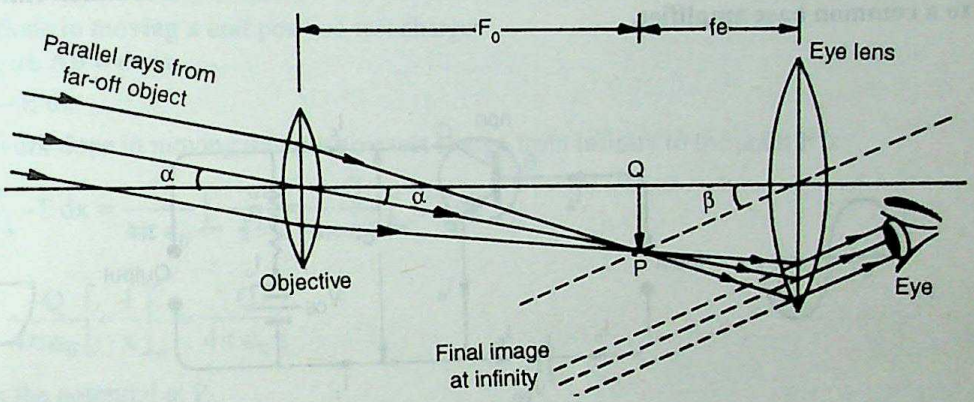
$$\text{Efficiency} = \frac{80}{100} = \frac{\text{Power output}}{\text{Power input}} = \frac{V_2 I_2}{V_1 I_1}$$

$$\Rightarrow \frac{80}{100} = \frac{20 \times 1}{200 \times I_1}$$

$$\Rightarrow I_1 = \frac{20}{80 \times 2} = \frac{1}{8} = 0{\cdot}125 \text{ A.}$$

Q. 17. Draw a ray diagram showing how the final image of a distant object is formed using an astronomical telescope in the near point position. **(2)**

Ans.



Q. 18. A spherical Gaussian surface encloses a charge of $8{\cdot}85 \times 10^{-8}$ C.

(i) Calculate the electric flux passing through the surface.

(ii) If the radius of the Gaussian surface is doubled, how would the flux change ? **(2)**

Ans. $Q = 8{\cdot}85 \times 10^{-8}$ C, $\epsilon_0 = 8{\cdot}85 \times 10^{-12} C^2 N^{-1} m^{-2}$

(i) $\phi_E = \dfrac{Q}{\epsilon_0} = \dfrac{8 \cdot 85 \times 10^{-8}}{8 \cdot 85 \times 10^{-12}} = 10^4 Nm^2C^{-1}$.

(ii) The flux does not depend upon the radius of the sphere. It only depends upon the amount of charge enclosed by the Gaussian surface . Hence, the flux will remain the same.

Q. 19. State the condition for diffraction of light to occur. In the diffraction at a single slit experiment, how would the width and the intensity of central maximum change if (i) slit width is halved (ii) visible light of longer wavelength is used ? **(1, 2)**

Ans. The condition for diffraction to occur is that the dimensions of the aperture or the obstacle are comparable with the wavelength of light.

(i) When slit width is halved, central maximum width is doubled and intensity becomes one-fourth.

(ii) When visible light of longer wavelength is used, central maximum width increases and intensity decreases.

Q. 20. A semiconductor has equal electron and hole concentration of $2 \times 10^8/m^3$. On doping with a certain impurity, the hole concentration increases to $4 \times 10^{10}/m^3$.

(i) What type of semiconductor is obtained on doping ?

(ii) Calculate the new electron concentration of the semiconductor.

(iii) How does the energy gap vary with doping ? **(3)**

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Ans. (i) p-type semiconductor is obtained.

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(ii) $n_i = 2 \times 10^8/m^3$, $n_h = 4 \times 10^{10}/m^3$, $n_e = ?$

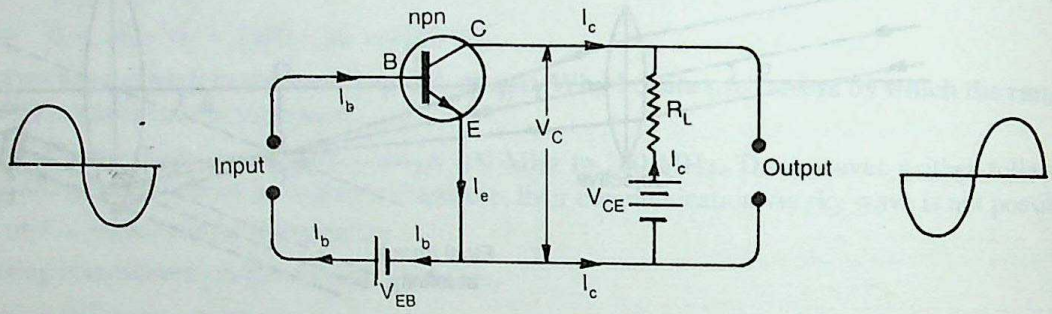
$n_i^2 = n_e \times n_h$

$$\Rightarrow \quad n_e = \frac{n_i^2}{n_h} = \frac{\left(2\times10^8\right)^2}{4\times10^{10}} = \mathbf{10^6/m^3}.$$

(iii) Energy gap decreases.

Q. 21. Draw the circuit diagram of a common emitter amplifier with appropriate biasing. What is the phase difference between the input and output signals. State two reasons why a common emitter amplifier is preferred to a common base amplifier. **(3)**

Ans.



The phase difference between input and output signals is 180°.

Common emitter amplifier is preferred to a common base amplifier due to

(i) high voltage gain,

(ii) high currant gain.

Q. 22. A parallel plate capacitor is charged to a potential difference V by a d.c. source. The capacitor is then disconnected from the source. If the distance between the plates is doubled, state with reason how the following will change :

(i) Electric field between the plates

(ii) Capacitance and

(iii) Energy stored in the capacitor. **(3)**

Ans. We know that $E = \frac{\sigma}{\epsilon_0}$, $C = \frac{\epsilon_0 A}{d}$, $U = \frac{1}{2}\frac{Q^2}{C}$

(i) If the distance between the plates is doubled, then, the electric field between the plates remains unchanged.

(ii) If the distance between the plates is doubled, then, the capacitance becomes half, since $C \propto \frac{1}{d}$

(iii) If the distance between the plates is doubled, capacitance becomes half, and consequently the energy stored in the capacitor is doubled.

Q. 23. Define 'electric potential'. Deduce an expression for the electric potential at a point distance 'r' from a point charge (Q > 0). **(3)**

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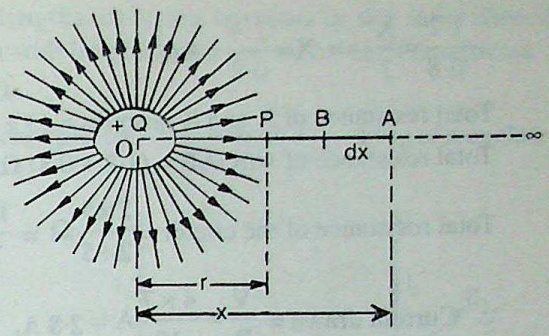
Ans. Electric potential : Electrostatic potential at a point in the field is the amount of work done in moving a unit positive test charge from infinity to that point against the electrostatic forces along any path.



Suppose a single point charge +Q is placed at a point O and P be a point distant r from O.

At any point A, on the line joining OP, where OA = x, the electric intensity, $E = \frac{1}{4\pi \epsilon_0}\frac{Q}{x^2}$.

Work done in moving a unit positive test charge from A to B, where AB = dx is

$dW = -E\,dx$

Total work done in moving unit positive test charge from infinity to the point P is

$$W = \int_{\infty}^{r} -E\,dx = \frac{Q}{4\pi \epsilon_0}\int_{\infty}^{r}\frac{-dx}{x^2} = \frac{-Q}{4\pi \epsilon_0}\int_{\infty}^{r} x^{-2}\,dx$$

$$= \frac{-Q}{4\pi \epsilon_0}\left[-\frac{1}{x}\right]_{\infty}^{r} = \frac{Q}{4\pi \epsilon_0 r}.$$

This is the potential at P.

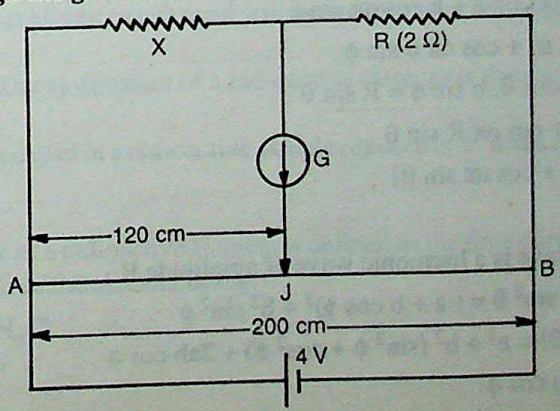
$$V = \frac{1}{4\pi \epsilon_0}\frac{Q}{r}.$$

Q. 24. Define resistivity and state its S.I. unit. State and explain how the resistivity of a conductor varies with temperature. (3)

Ans. Resistivity : Resistivity of the material of a conductor is defined as the resistance of unit length and unit area of cross-section of the conductor. Its S.I. unit is ohm-m.

In most metals number density n of free electrons does not change with temperature but due to increase in temperature, the amplitude of vibration of lattice ions of the metal increases. Due to which the collision of free electrons with ions while drifting towards the positive end of the conductor becomes more frequent, which results decrease in relaxation time. Hence, resistivity of conductors increases with increase in temperature.

Q. 25. Find the value of the unknown resistance X and the current drawn by the circuit from the battery, if no current flows through the galvanometer. Assume the resistance per unit length of the wire AB to 0.01 Ω/cm. (3)



Ans. Resistance of wire AJ = $(120 \times 0{\cdot}01)\,\Omega = 1{\cdot}2\,\Omega$

Resistance of wire BJ = $(80 \times 0{\cdot}01)\,\Omega = 0{\cdot}8\,\Omega$

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In the balance position

$$\frac{1\cdot2}{0\cdot8}=\frac{X}{2} \Rightarrow X=\frac{2\cdot4}{0\cdot8}=3\,\Omega$$

Total resistance of X and R in series = (3 + 2) Ω = 5 Ω

Total resistance of wire AB = (1·2 + 0·8) Ω = 2 Ω

Total resistance of the circuit $=\frac{2\times5}{2+5}\Omega=\frac{10}{7}\Omega$.

$\therefore$ Current drawn $=\frac{V}{R}=\frac{4\times7}{10}A=2\cdot8$ A.

Q. 26. The ground state energy of hydrogen atom is –13.6 eV. If an electron makes a transition from an energy level –0.85 eV to –3.4 eV, calculate the wavelength of the spectral line emitted. To which series of hydrogen spectrum, does this wavelength belong ? (3)

Ans. $E_1 = -3.4$ eV, $E_2 = -0.85$ eV, $h = 6.6 \times 10^{-34}$ Js, $c = 3 \times 10^8$ m/s

$E_2 - E_1 = (-0.85 + 3.4)$ eV $= 2.55$ eV $= 2.55 \times 1.6 \times 10^{-19}$ J.

We have, $\frac{hc}{\lambda} = E_2 - E_1$

$$\Rightarrow \lambda = \frac{hc}{E_2 - E_1} = \frac{6\cdot6\times10^{-34}\times3\times10^8}{2\cdot55\times1\cdot6\times10^{-19}} = 4.853 \times 10^{-7}\text{ m} = 4853\text{ Å}.$$

This wavelength corresponds to Balmer series of hydrogen atom.

Q. 27. What are coherent sources of light ? Deduce an expression for the intensity at any point on the screen in Young's double slit experiment. (1, 2)

Ans. Coherent sources : The sources of light, which emit continuous light waves of the same wavelength, same frequency and in same phase or having a constant phase difference are called coherent sources.

Let the waves from two coherent sources of light be

$Y_1 = a \sin \omega t$ -------- (i)

$Y_2 = b \sin (\omega t + \phi)$ ------- (ii)

According to super position principle, the displacement of resultant wave Y is given by

$Y = Y_1 + Y_2 = a \sin \omega t + b \sin (\omega t + \phi)$

$= a \sin \omega t + b \sin \omega t \cos \phi + b \cos \omega t \sin \phi$

$= \sin \omega t (a + b \cos \phi) + \cos \omega t\, b \sin \phi$

Let $a + b \cos \phi = R \cos \theta$, $b \sin \phi = R \sin \theta$

$Y = \sin \omega t\ R \cos \theta + \cos \omega t\ R \sin \theta$

$= R [\sin \omega t \cos \theta + \cos \omega t \sin \theta]$

$Y = R \sin (\omega t + \theta)$

Thus, the resultant wave is a harmonic wave of amplitude R.

Also, $R^2 \cos^2 \theta + R^2 \sin^2 \theta = (a + b \cos \phi)^2 + b^2 \sin^2 \phi$

$\Rightarrow R^2 (\cos^2 \theta + \sin^2 \theta) = a^2 + b^2 (\sin^2 \phi + \cos^2 \phi) + 2ab \cos \phi$

$\Rightarrow R^2 = a^2 + b^2 + 2ab \cos \phi$

Also, $I \propto R^2$

$\Rightarrow I \propto a^2 + b^2 + 2ab \cos \phi$

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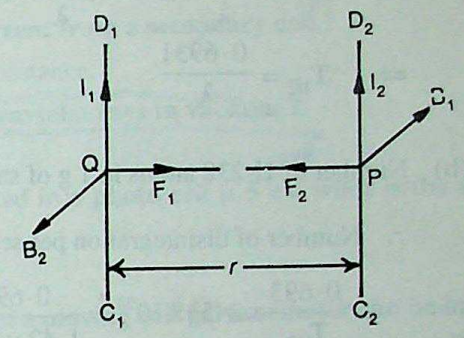
Q. 28. Prove that two parallel conductors of infinite lengths, carrying currents in the same direction attract each other. Deduce the expression for the force per unit length, experienced by each conductor. (5)

Or

Explain with the help of a labelled diagram the principle, construction and working of a cyclotron. (5)

Ans. Consider C_1D_1 and C_2D_2 two infinite long straight conductors carrying currents I_1 and I_2 in the same direction C_1D_1 and C_2D_2 are held parallel to each other at a distance r apart. Since each conductor is in the magnetic field produced by the other, therefore, each conductor experiences a force.



Magnetic field at a point P on conductor C_2D_2 due to current I_1 passing through C_1D_1 is given by

$$B_1 = \frac{\mu_0}{4\pi}\frac{2I_1}{r}$$

According to right hand rule, the direction of magnetic field B_1 is perpendicular to the plane of paper directed inwards.

The unit length of current carrying conductor C_2D_2 will experience a fore given by

$$F_2 = B_1 I_2 \times l = B_1 I_2$$

$$\Rightarrow F_2 = \frac{\mu_0}{4\pi}\frac{2I_1 I_2}{r} \quad \text{-------- (i)}$$

Direction of force on conductor C_2D_2 is given by Fleming's left hand rule, which acts in the plane of paper perpendicular to C_2D_2 directed towards C_1D_1.

Similarly, it can be shown that the conductor C_1D_1 also experiences a force given by (i) which act in the plane of paper perpendicular to C_1D_1 and directed towards C_2D_2.

Hence, C_1D_1 and C_2D_2 attract each other.

Or

See chapter 4 for the answer.

Q. 29. (a) Define the terms decay constant and half-life of a radioactive sample. Derive the relation connecting the two. (3)

(b) How many disintegrations per second will occur in one gram of $_{92}U^{238}$, if its half-life against alpha decay is 1.42×10^{17} s ? (2)

Ans. (a) Decay constant : Decay constant of a radioactive element is the reciprocal of time at the end of which the number of atoms left undecayed in a radioactive sample reduces to $\frac{1}{e}$ times the original number of atoms in the sample.

Half-life : Half-life of a radioactive element is defined as the time during which half the number of atoms present initially in the sample of the element decay.

For $t = T_{1/2}$, $N = N_0/2$.

Now, $N = N_0 e^{-\lambda t}$

$$\Rightarrow \frac{N_0}{2} = N_0 e^{-\lambda T_{1/2}}$$

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$$\Rightarrow \quad \frac{1}{2} = e^{-\lambda T_{1/2}} \quad \Rightarrow \quad 2 = e^{\lambda T_{1/2}}$$

$$\Rightarrow \quad \lambda T_{1/2} = \log_e 2.$$

$$\Rightarrow \quad T_{1/2} = \frac{\log_e 2}{\lambda} = \frac{2 \cdot 3026 \times \log_{10} 2}{\lambda}.$$

$$\Rightarrow \quad T_{1/2} = \frac{0 \cdot 6931}{\lambda}.$$

(b) Number of U-238 atoms in 1 g of sample $= \frac{6 \cdot 023 \times 10^{23}}{238} = 2 \cdot 53 \times 10^{21}$ atoms.

$\therefore$ Number of disintegration per second $= \lambda \times 2 \cdot 53 \times 10^{21}$

$$= \frac{0 \cdot 693}{T_{1/2}} \times 2 \cdot 53 \times 10^{21} = \frac{0 \cdot 693}{1 \cdot 42 \times 10^{17}} \times 2 \cdot 53 \times 10 = \mathbf{1 \cdot 23 \times 10^4\ s^{-1}}.$$

Q. 30. Derive an expression for the self-inductance of a long solenoid.

An inductor L, a capacitor 20 μF, a resistor 10 Ω are connected in series with an a.c. source of frequency 50 Hz. If the current is in phase with the voltage, calculate the inductance of the inductor. (3, 2)

Ans. Consider a long solenoid of length ℓ, number of turns N and radius r.

Let the current flowing through it be I.

The magnetic field B at any point inside such a solenoid is

$$B = \frac{\mu_0 NI}{\ell}$$

$\therefore$ Magnetic flux through each turn of the solenoid coil = B × Area of each coil $= \frac{\mu_0 NIA}{\ell}$

Total magnetic flux linked with the solenoid = Flux through each turn × Total number of turns.

$$\phi = \frac{\mu_0 NIA}{\ell} \times N$$

Also, $\phi = LI$, where L is the self inductance of the solenoid.

$$\Rightarrow \quad LI = \frac{\mu_0 NIA}{\ell} \times N$$

$$\Rightarrow \quad L = \frac{\mu_0 N^2 A}{\ell}$$

Numerical : f = 50 Hz, C = 20 μF = 20 × 10^{-6} F

We have, $X_L = X_C \quad \Rightarrow \quad 2\pi fL = \frac{1}{2\pi fC}$

$$\Rightarrow \quad L = \frac{1}{4\pi^2 f^2 C}$$

$$= \frac{1}{4 \times 9 \cdot 87 \times (50)^2 \times 20 \times 10^{-6}} = \mathbf{0 \cdot 5\ H}.$$

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SET II — 2001 (DELHI BOARD)

Time allowed : 3 hours **Max. Marks : 70**

General Instructions :

Same as Delhi Board Set — I, 2001

Note : Except for the following questions, all the remaining questions have been asked in Set — I.

Q. 2. Under what condition, can we draw maximum current from a secondary cell ? **(1)**

Ans. When its internal resistance is equal to the external resistance.

Q. 5. What is the ratio of speed of infrared rays and ultraviolet rays in vacuum ? **(1)**

Ans. 1 : 1

Q. 6. If the maximum kinetic energy of electrons emitted in a photo cell is 5 eV, what is the stopping potential ? **(1)**

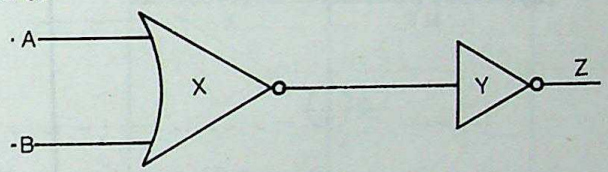
Ans. Stopping potential is also 5 V.

Q. 7. Give two factors by which the current sensitivity of a moving coil galvanometer can be increased. **(1)**

Ans. (i) By increasing the magnetic field strength of the magnet.

(ii) By increasing the number of turns of the galvanometer coil.

Q. 11. Identify the logic gates marked X, Y in the following figure. Write down the output at Z, when A = 1, B = 1 and A = 0, B = 0. **(2)**

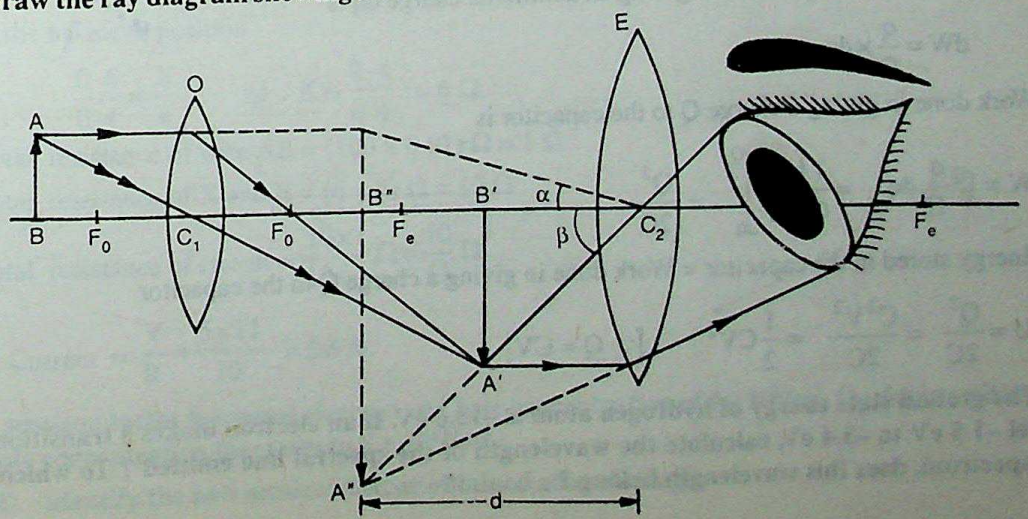


Ans. X is NOR gate and Y is NOT gate.

A	B	$Y = \overline{A+B}$	$Z = \overline{Y}$
1	1	0	1
0	0	1	0

Q. 12. Draw the ray diagram showing the formation of image of an object using a compound microscope. **(2)**

Ans.



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Q. 14. A thin converging lens has a focal length 'f' in air. If it is completely immersed in a liquid, briefly explain how the focal length of the lens will vary ? (2)

Ans. We know that $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

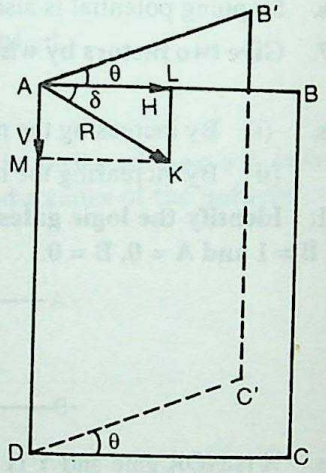
$$\Rightarrow \quad f \propto \frac{1}{\mu - 1}$$

Since, the refractive index of glass w.r.t. water is less than the refractive index of glass w.r.t. air, therefore, focal length of the lens in water will be more than that in air.

Q. 17. Define the term 'angle of dip'. Derive the relation between angle of dip and the resultant magnetic field of earth at a place. (2)

Ans. The angle of dip at any place on the earth is the angle between the resultant magnetic field on earth and the horizontal direction at that place.

In the figure, AK represents total intensity of earth's magnetic field.



$\angle BAK = \delta$.

Horizontal component along AB

is $H = R \cos \delta$ ---------- (i)

Vertical component along AD

is $V = R \sin \delta$ --------- (ii)

From (i) and (ii)

$$\tan \delta = \frac{V}{H}$$

Q. 19. Prove that the energy stored in a parallel plate capacitor is $\frac{1}{2} CV^2$. (3)

Ans. Suppose the capacitor is charged gradually, at an instant the charge on the capacitor is q.

Potential of capacitor = $\frac{q}{C}$

Small amount of work done in giving an additional charge dq is

$$dW = \frac{q}{C} \times dq$$

Work done in giving a charge Q to the capacitor is

$$W = \int_0^Q \frac{q}{C}\, dq \quad = \frac{1}{C}\left[\frac{q^2}{2}\right]_0^Q \quad = \frac{Q^2}{2C}$$

Energy stored in the capacitor = Work done in giving a charge Q to the capacitor

$$U = \frac{Q^2}{2C} \quad = \frac{C^2V^2}{2C} \quad = \frac{1}{2}CV^2 \qquad [\because\ Q = CV]$$

Q. 20. The ground state energy of hydrogen atom is –13.6 eV. If an electron makes a transition from an energy level –1.5 eV to –3.4 eV, calculate the wavelength of the spectral line emitted ? To which series of hydrogen spectrum, does this wavelength belong ? (3)

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Ans. $E_1 = -3.4$ eV, $E_2 = -1.5$ eV. $h = 6.6 \times 10^{-34}$ Js, $c = 3 \times 10^8$ m/s

$$\frac{hc}{\lambda} = E_2 - E_1$$

$$\Rightarrow \lambda = \frac{hc}{E_2 - E_1} = \frac{6{\cdot}6\times10^{-34}\times3\times10^{8}}{(-1{\cdot}5+3{\cdot}4)\times1{\cdot}6\times10^{-19}}$$

$$= = \frac{6{\cdot}6\times3\times10^{-26}}{1{\cdot}9\times1{\cdot}6\times10^{-19}} = 6{\cdot}513\times10^{-7}\ \text{m} = \mathbf{6513\ Å.}$$

This wavelength corresponds to Balmer series of hydrogen spectrum.

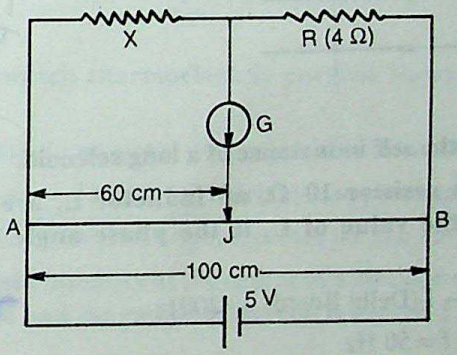
Q. 21. Define 'conductivity' of a conductor and state its S.I. unit. State and explain the variation of conductivity of ionic conductor with temperature. **(3)**

Ans. Conductivity : The inverse of resistivity (ρ) of a conductor is called its electrical conductivity.

Its S.I. unit is mho-m^{-1}.

As the temperature increases the electrostatic attraction between cations and anions decreases. So the ions are more free to move. Hence, as the temperature increases, conductivity of an ionic conductor increases.

Q. 22. Calculate the value of unknown resistance X and the current drawn by the circuit, assuming that no current flows through the galvanometer. Assume the resistance per unit length of the wire AB to be 0·01 Ω/cm. **(3)**



Ans. Resistance of wire AJ = $(60 \times 0{\cdot}01)\ \Omega = 0{\cdot}6\ \Omega$

Resistance of wire BJ = $(40 \times 0{\cdot}01)\ \Omega = 0{\cdot}4\ \Omega$

In the balanced position

$$\frac{0{\cdot}6}{0{\cdot}4} = \frac{X}{4} \quad \Rightarrow X = \frac{2{\cdot}4}{0{\cdot}4} = \mathbf{6\ \Omega.}$$

Total resistance of wire AB = $(100 \times 0{\cdot}01)\ \Omega = 1\ \Omega$

Total resistance of X and R = $(6 + 4)\ \Omega = 10\ \Omega$

Total resistance of circuit = $\frac{10\times1}{10+1}\Omega = \frac{10}{11}\Omega$

$$\therefore \text{Current} = \frac{V}{R} = \frac{5\times11}{10} = \mathbf{5{\cdot}5\ A.}$$

Q. 24. A semiconductor has equal electron and hole concentration of $4 \times 10^8/m^3$. On doping with a certain impurity, hole concentration increases to $8 \times 10^{12}/m^3$:

(i) Identify the new semiconductor obtained after doping,

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(ii) Calculate the new electron concentration and

(iii) How does the energy gap vary with doping ? (3)

Ans. (i) The new semiconductor obtained is p-type.

(ii) $n_i = 4 \times 10^8/m^3$, $n_h = 8 \times 10^{12}/m^3$.

$n_i^2 = n_h n_e$

$$\Rightarrow \quad n_e = \frac{n_i^2}{n_h} = \frac{(4\times10^8)^2}{8\times10^{12}} = 2 \times 10^4/m^3.$$

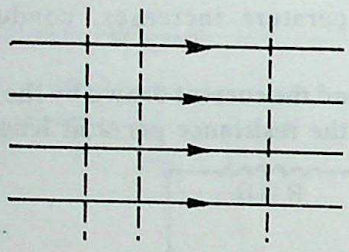
(iii) With doping energy gap decreases.

Q. 27. (a) Why two electric lines of force do not intersect each other ? (1)

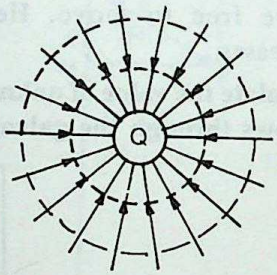
(b) Draw one equipotential surface (i) in a uniform electric field and (ii) for a point charge (Q < 0). (2)

Ans. (a) Two lines of electric force never intersect each other. If they do, so then there will be two directions of electric field at the point of intersection, which is not possible.

(b) (i)



(ii)



Q. 28. Derive the expression for the self inductance of a long solenoid.

A capacitor of 50 μF, a resistor 10 Ω, an inductor L, are in series with an a.c. source of frequency 50 Hz. Calculate the value of L, if the phase angle between current and voltage is zero. (3, 2)

Ans. For 1st part see Q. 30. Set — I (Delhi Board) — 2001

$C = 50\ \mu F = 50 \times 10^{-6}$ F, $f = 50$ Hz

$$X_L = X_C \quad \Rightarrow \quad 2\pi fL = \frac{1}{2\pi fC}$$

$$\Rightarrow \quad L = \frac{1}{4\pi^2 f^2 C} = \frac{1}{4\times9{\cdot}87\times(50)^2\times50\times10^{-6}} = 0{\cdot}2\ \text{H}.$$

SET III — 2001 (DELHI BOARD)

All the questions have been answered in Set I and Set II.

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PHYSICS (THEORY)

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C.B.S.E. CLASS XII (SET I) — 2001 (OUTSIDE DELHI)

Time allowed : 3 hours **Max. Marks : 70**

General Instructions :

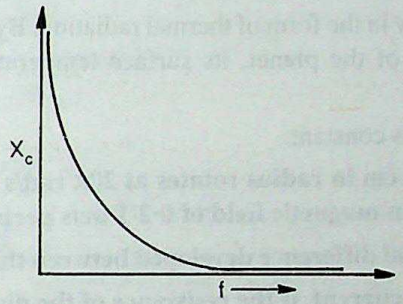
Same as Delhi Board Set — I, 2001.

Q. 1. State the reason why ground waves cannot be transmitted above the frequency range of 1500 kHz. **(1)**

Ans. Ground wave transmission is restricted to frequencies less than 1500 kHz, because at higher frequencies intensity of these waves decreases.

Q. 2. Draw a graph to show the variation of capacitive reactance with frequency of an a.c. source. **(1)**

Ans.



Q. 3. Give the direction in which thermoelectric current flows at the hot junction of a Cu–Fe thermocouple. **(1)**

Ans. The direction of thermoelectric current at the hot junction is from Cu to Fe.

Q. 4. Two stars have magnitudes – 3 and + 6. Which star appears to be less bright ? **(1)**

Ans. The star having magnitude + 6 has less brightness than the star having magnitude – 3.

Q. 5. How will the magnetic field intensity at the centre of a circular coil carrying current change, if the current through the coil is doubled and the radius of the coil is halved ? **(1)**

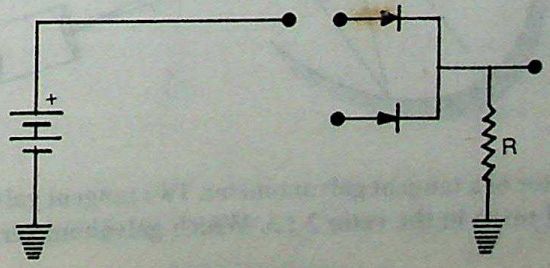
Ans. We know that $B = \frac{\mu_0 nI}{2r}$

When I is doubled and the radius of the coil is halved, then magnetic field B will become four times of the original field.

Q. 6. What orientation of an electric dipole in a uniform electric field corresponds to its stable equilibrium ? **(1)**

Ans. In stable equilibrium, the electric dipole is situated parallel to the uniform electric field.

Q. 7. Name the logic gate realized using p-n junction diodes in the given diagram. Give its logic symbol. **(1)**



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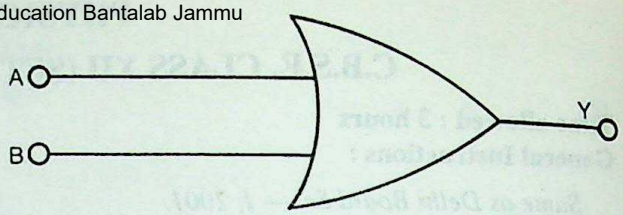
Ans. It is OR gate. Its logic symbol is shown below.



Q. 8. State two properties of the material of the wire used for suspension of the coil in a moving coil galvanometer. (1)

Ans. The suspension wire should have,

(i) high strength. (ii) low restoring torque per unit twist.

Q. 9. Explain briefly how the surface temperature of a planet can be determined. (2)

Ans. The surface temperature of a planet can be determined by using Stefan's fourth power law.

Every planet radiates energy in the form of thermal radiation. By knowing the amount of thermal energy E emitted per second per unit area of the planet, its surface temperature T can be calculated by using the following relation

$E = \sigma T^4$, where σ is Stefan's constant.

Q. 10. A circular copper disc 10 cm in radius rotates at 20π rad/s about an axis through its centre and perpendicular to the disc. A uniform magnetic field of 0·2 T acts perpendicular to the disc.

(i) Calculate the potential difference developed between the axis of the disc and the rim.

(ii) What is the induced current, if the resistance of the disc is 2 ohm ? (2)

Ans. $r = 10\text{ cm} = 0{\cdot}1\text{ m}$, $\omega = 20\,\pi$ rad/s, $B = 0{\cdot}2$ T

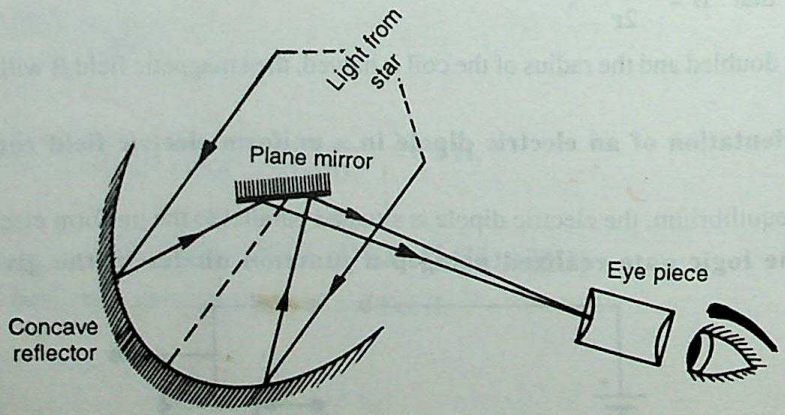
(i) P. D. developed between the axis of the disc and the rim $= \frac{1}{2} B r^2 \omega$

$= \frac{1}{2} \times 0{\cdot}2 \times (0{\cdot}1)^2 \times 20 \times 3{\cdot}14$ **= 0·0628 V.**

(ii) Induced current $= \frac{V}{R} = \frac{0{\cdot}0628}{2}$ **= 0·0314 A.**

Q. 11. Draw a labelled ray diagram of a Newtonian type reflecting telescope. (2)

Ans.



Q. 12. Define reduction factor of a tangent galvanometer. Two tangent galvanometers, of the same radius of coils, have their number of turns in the ratio 2 : 3. Which galvanometer has larger value of reduction factor ? (2)

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Ans. Reduction factor : Reduction factor of a tangent galvanometer may be defined as the current to be passed through galvanometer to produce a deflection of 45°.

Numerical : $K_1 = \frac{2r_1 H}{n_1 \mu_0}, \quad K_2 = \frac{2r_2 H}{n_2 \mu_0}$

$$\frac{K_1}{K_2} = \frac{r_1}{r_2} \cdot \frac{n_2}{n_1} = \frac{1}{1} \cdot \frac{3}{2} \qquad \left[\frac{n_1}{n_2} = \frac{2}{3}\right]$$

$$\Rightarrow \quad \frac{K_1}{K_2} = \frac{3}{2}.$$

Hence, first galvanometer has higher reduction factor.

Q. 13. A ray of light incident on an equilateral glass prism shows minimum deviation of 30°. Calculate the speed of light through the glass prism. (2)

Ans. Since, the prism is equilateral, therefore,

$A = 60°, \ \delta m = 30°, c = 3 \times 10^8$ m/s

$$\mu = \frac{\sin\frac{A+\delta m}{2}}{\sin A/2} = \frac{\sin\frac{60°+30°}{2}}{\sin 30°} = \frac{\frac{1}{\sqrt{2}}}{\frac{1}{2}} = \sqrt{2} = 1{\cdot}41.$$

Speed of light in glass $= \frac{c}{\mu} = \frac{3\times10^8}{1{\cdot}41} = \mathbf{2{\cdot}1 \times 10^8 \ m/s.}$

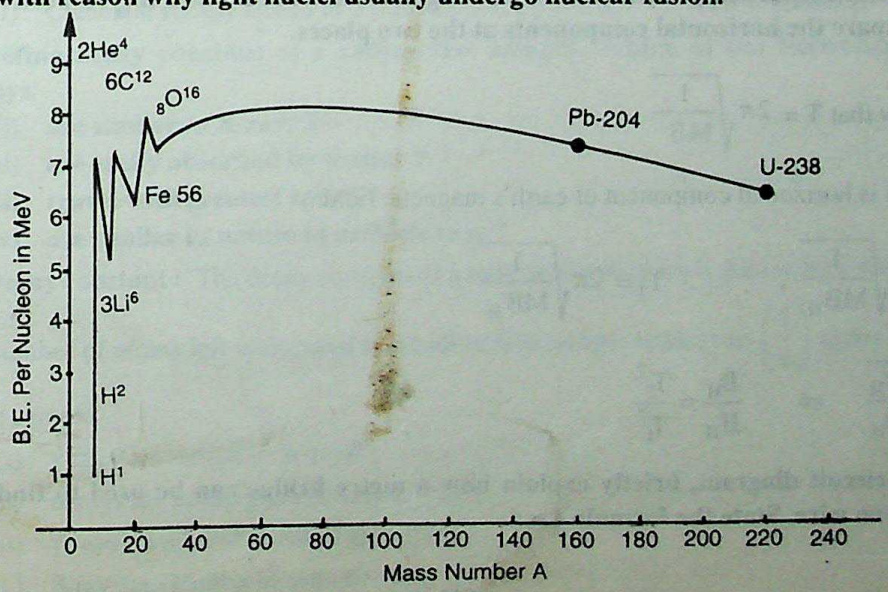
Q. 14. What is meant by the term, doping of an intrinsic semiconductor ? How does it affect the conductivity of a semiconductor ? (2)

Ans. Doping is a process of deliberate addition of a desirable impurity to a pure semiconductor to modify its properties in a controlled manner. The impurity atoms added are called dopants.

Doping of a semiconductor increases its electrical conductivity to a great extent.

Q. 15. Draw a diagram to show the variation of binding energy per nucleon with mass number for different nuclei. State with reason why light nuclei usually undergo nuclear fusion. (2)

Ans.



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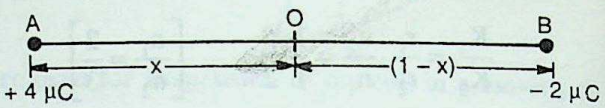
Since, binding energy per nucleon of light nuclei is small, therefore, in attempt to have higher binding energy per nucleon, these nuclei undergo nuclear fusion.

Q. 16. Two point charges 4 μC, – 2 μC are separated by a distance of 1 m in air. At what point on the line joining the charges is the electric potential zero ? (2)

Ans. Let the charges of + 4 μC and – 2 μC are placed at A and B respectively.



Let O be a point on the line joining the point A and B, at a distance of x m from A, where the electric potential is zero.

Thus, $\frac{1}{4\pi\epsilon_0}\left[\frac{4\times10^{-6}}{x}-\frac{2\times10^{-6}}{1-x}\right]=0$

$\Rightarrow \quad \frac{4}{x}-\frac{2}{1-x}=0 \quad \Rightarrow \frac{2}{x}=\frac{1}{1-x}$

$\Rightarrow \quad 2-2x=x \quad \Rightarrow \quad x=2/3$

Hence, at a distance of 2/3 m from + 4 μC charge, the electric potential is zero.

Q. 17. If the output of a 2-input NAND gate is fed as the input to a NOT gate (i) name the new logic gate obtained and (ii) write down its truth table. (2)

Ans. (i) The new logic gate obtained is AND gate.

(ii) Truth table is given below.

A	B	$Y=\overline{A\cdot B}$	$Y'=\overline{Y}$
0	0	1	0
0	1	1	0
1	0	1	0
1	1	0	1

Q. 18. A magnet makes angular oscillations in a horizontal plane with time periods T_1 and T_2 at two places, where the horizontal components of earth's magnetic field are B_H and B'_H respectively. Deduce an expression to compare the horizontal components at the two places. (2)

Ans. We know that $T=2\pi\sqrt{\frac{I}{MB}}$

Where B is horizontal component of earth's magnetic field.

$T_1=2\pi\sqrt{\frac{I}{MB_H}}, \qquad T_2=2\pi\sqrt{\frac{I}{MB'_H}}$

$\frac{T_1}{T_2}=\sqrt{\frac{B'_H}{B_H}} \quad \Rightarrow \quad \frac{B_H}{B'_H}=\frac{T_2^2}{T_1^2}$

Q. 19. With a circuit diagram, briefly explain how a metre bridge can be used to find the unknown resistance of a given wire. State the formula used. (3)

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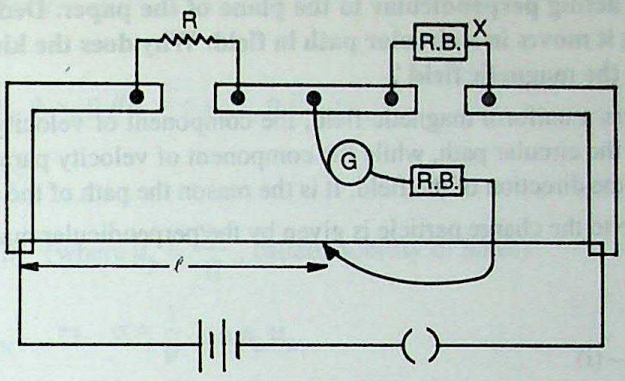
Ans. The required circuit diagram is shown below.



Using jockey locate null point on wire after taking a known resistance X from resistance box. Let null length be l, then $\frac{R}{l} = \frac{X}{100 - l}$.

$$\Rightarrow \quad R = X\left(\frac{l}{100 - l}\right).$$

Q. 20. A storage battery of emf 8 V, internal resistance 1 Ω, is being charged by a 120 V d.c. source, using a 15 Ω resistor in series in the circuit. Calculate :

(i) the current in the circuit,

(ii) terminal voltage across the battery during charging, and

(iii) chemical energy stored in the battery in 5 minutes. **(3)**

Ans. Net emf of the battery = (120 – 8) V = 112 V

Total resistance of circuit = (1 + 15) Ω = 16 Ω

(i) Current in the circuit, $I = \frac{112}{16} = 7$ **A.**

(ii) Terminal voltage during charging = 8 + I × r = 8 + 7 × 1 = **15 V**

(iii) Chemical energy stored in 5 minutes = E·I·t = 8 × 7 × 5 × 60 = **16800 J.**

Q. 21. Define decay constant of a radioactive sample. Which of the follwoing radiations, α-rays, β-rays, γ-rays

(i) are similar to X-rays ?

(ii) are easily absorbed by matter ?

(iii) travel with greatest speed ?

(iv) are similar in nature to cathode rays ? **(3)**

Ans. Decay constant : The decay constant of a radioactive element is the reciprocal of the time at the end of which the number of atoms left undecayed in a radioactive sample reduces to $\left(\frac{1}{e}\right)$ times the original number of atoms in the sample.

(i) γ-rays are similar to X-rays.

(ii) α-rays are easily absorbed by matter.

(iii) γ-rays travel with greatest speed.

(iv) β-rays are similar to cathode rays.

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Q. 22. A particle with charge 'q', moving with a velocity 'v', moving in the plane of paper enters a uniform magnetic field 'B', acting perpendicular to the plane of the paper. Deduce an expression for the time period of the charge, as it moves in a circular path in field. Why does the kinetic energy of the charge not change, while moving in the magnetic field ? **(3)**

Ans. When a charge enters a uniform magnetic field, the component of velocity perpendicular to the field makes the charge move along the circular path, while the component of velocity parallel to the direction of field makes the charge move along the direction of the field. It is the reason the path of the charge is a helix.

The centripetal force to the charge particle is given by the perpendicular magnetic field. Therefore,

$$qBv \sin 90° = \frac{mv^2}{r}$$

$$\Rightarrow \quad r = \frac{mv}{qB} \quad \text{------- (i)}$$

$$\text{Also,} \quad T = \frac{\text{Circumference}}{\text{Velocity}} = \frac{2\pi r}{v} = \frac{2\pi}{v} \cdot \frac{mv}{qB} \quad \text{[from --(i)]}$$

$$\Rightarrow \quad T = \frac{2\pi m}{qB}$$

Since no net work is done by the magnetic field on the charge particle, therefore, the kinetic energy of the charge particle does not change.

Q. 23. How can a moving coil galvanometer be converted into an ammeter ? To increase the current sensitivity of a moving coil galvanometer by 50%, its resistance is increased so that the new resistance becomes twice its initial resistance. By what factor does its voltage sensitivity change ? **(3)**

Ans. A moving coil galvanometer can be converted into an ammeter by connecting a small resistance in parallel with it.

$$\text{Voltage sensitivity, } V_s = \frac{I_s}{R}$$

$$\text{New current sensitivity, } I'_s = I_s + \frac{50 \times I_s}{100} = \frac{3I_s}{2}$$

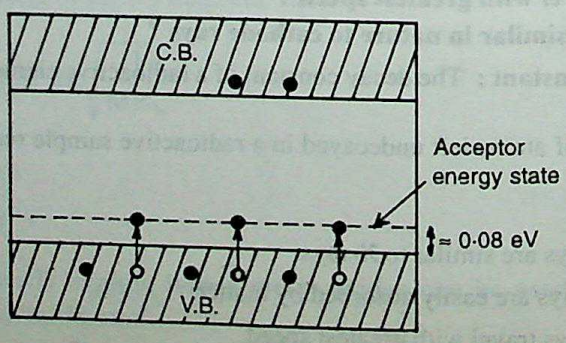
$$\text{New resistance, } R' = 2R$$

$$\therefore \quad \text{New voltage sensitivity, } V'_s = \frac{3I_s}{2 \times 2R} = \frac{3I_s}{4R}$$

$$\therefore \quad \frac{V'_s}{V_s} = \frac{3}{4} \quad \Rightarrow \quad V'_s = \frac{3}{4} V_s$$

Q. 24. Draw the energy band diagram of a p-type semiconductor. Deduce an expression for the conductivity of a p-type semiconductor. **(1+2)**

Ans.



Energy band diagram of a p-type semiconductor.

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A p-type semiconductor has holes as the majority carriers.

$\therefore \quad I = I_h = e\, n_h\, A\, v_h$

$R = \rho \dfrac{l}{A}$

$\therefore \quad V = IR = e\, n_h\, A\, v_h\, \rho\, l/A = e\, n_h\, v_h\, \rho\, l$

$E = \dfrac{V}{l} = e\, n_h\, v_h\, \rho$

$\Rightarrow \quad 1 = e\, n_h\, \mu_h\, \rho \quad \left(\text{where } \mu_h = \dfrac{v_h}{E}, \text{ called mobility of holes}\right)$

$\Rightarrow \quad \dfrac{1}{\rho} = e\, n_h\, \mu_h \quad \Rightarrow \quad \sigma = \dfrac{1}{\rho} = e\, n_h\, \mu_h.$

Q. 25. Where should an object be placed from a converging lens of focal length 20 cm, so as to obtain a real image of magnification 2 ? **(3)**

Ans. $f = 20\text{ cm}, \quad m = -2, \quad u = ?$

$m = \dfrac{f}{f+u} \quad \Rightarrow \quad \dfrac{20}{20+u} = -2$

$\Rightarrow \quad 20 = -40 - 2u$

$\Rightarrow \quad 2u = -60 \quad \Rightarrow \quad u = -30.$

Hence, the object should be placed at a distance of 30 cm from the converging lens.

Q. 26. State the essential condition for diffraction of light to occur.

The light of wavelength 600 nm is incident normally on a slit of width 3 mm. Calculate the linear width of central maximum on a screen kept 3 m away from the slit. **(3)**

Ans. The essential condition for diffraction to occur is that the dimensions of the aperture or the obstacle are comparable with the wavelength of light.

Numerical : $\lambda = 600\text{ nm} = 6 \times 10^{-7}\text{ m}, \quad d = 3\text{ mm} = 3 \times 10^{-3}\text{ m}, \quad D = 3\text{ m}.$

Linear width of central maximum $= \dfrac{2D\lambda}{d} = \dfrac{2 \times 3 \times 6 \times 10^{-7}}{3 \times 10^{-3}} = 1{\cdot}2 \times 10^{-3}\text{ m}.$

Q. 27. (a) State the postulates of Huygens' wave theory.

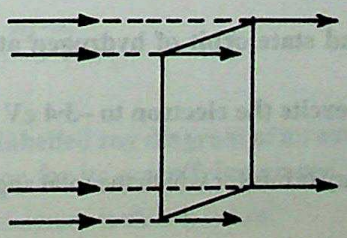
(b) Draw the type of wavefront that corresponds to a beam of light (i) coming from a very far-off source and (ii) diverging from a point source. **(3)**

Ans. (a) Postulates of Huygens' wave theory are :

(i) Every point on the given wavefront (called primary wavefront) acts as a fresh source of new disturbance, called secondary wavelets, which travel in all directions with the velocity of light in the medium.

(ii) A surface touching these secondary wavelets, tangentially in the forward direction at any instant gives the new wavefront at that instant. This is called secondary wavefront.

(b) (i)



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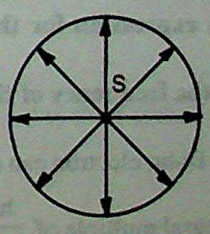

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Q. 28. State Gauss's theorem. Give its mathematical expression. Derive an expression for the electric field intensity at any point due to an infinite plane sheet of charge of charge density σ C/m^2. (5)

Or

Derive the expression for the capacitance of a parallel plate capacitor with a dielectric medium of dielectric constant 'k' between its plates. Obtain also the expression for the energy stored in the above case.

Ans. Gauss' theorem : Total electric flux over the closed surface S in vacuum is $\frac{1}{\epsilon_0}$ times the total charge q contained inside S

$$\phi_E = \oint \vec{E} \cdot d\vec{S} = \frac{q}{\epsilon_0}$$

For remaining part of the question see unit — I.

Q. 29. Prove that an ideal inductor does not dissipate power in an a.c. circuit.

A bulb of resistance 10 Ω, connected to an inductor of inductance L, is in series with an a.c. source marked 100 V, 50 Hz. If the phase angle between the voltage and current is $\frac{\pi}{4}$ radian, calculate the value of L. (5)

Ans. Work done in complete cycle is

$$W = \int_0^T E \cdot I \, dt$$

If the alternating voltage is

$E = E_0 \sin \omega t$ then, through L current lags behind E by a phase angle of $\pi/2$.

$\therefore \quad I = I_0 \sin(\omega t - \pi/2) = -I_0 \cos \omega t.$

$$W = -\int_0^T E_0 \sin \omega t \, I_0 \cos \omega t \, dt = -\frac{E_0 I_0}{2} \int_0^T 2 \sin \omega t \cos \omega t \, dt$$

$$= -\frac{E_0 I_0}{2} \left[-\frac{\cos 2\omega t}{2\omega} \right]_0^T = -\frac{E_0 I_0}{2} \times 0 = 0$$

$$\therefore \quad P = \frac{W}{T} = 0$$

Numerical : $R = 10\,\Omega$, $f = 50$ Hz, $\phi = \pi/4$, $L = ?$

$$\tan \phi = \frac{2\pi f L}{R} \quad \Rightarrow \quad \tan \frac{\pi}{4} = \frac{2 \times 3{\cdot}14 \times 50 \times L}{10}$$

$$\frac{2\pi f L}{R} \quad \Rightarrow \quad \tan \frac{\pi}{4} = \frac{2 \times 3{\cdot}14 \times 50 \times L}{10}.$$

Q. 30. Derive the expression for the radius of the ground state orbit of hydrogen atom, using Bohr's postulates.

Calculate the frequency of the photon, which can excite the electron to –3·4 eV from – 13·6 eV. (5)

Ans. According Bohr, electron can revolve only in stationary orbits for which the total angular momentum of the electron is an integral multiple of $\frac{h}{2\pi}$, where h is Planck's constant.

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$$\therefore \quad mvr = \frac{nh}{2\pi}$$

$$\Rightarrow \quad v = \frac{nh}{2\pi mr} \qquad \text{------ (i)}$$

$$\text{Also,} \quad \frac{mv^2}{r} = \frac{kZe^2}{r^2}, \qquad \left[\text{where } k = \frac{1}{4\pi \epsilon_0}\right]$$

$$\Rightarrow \quad m\left(\frac{nh}{2\pi mr}\right)^2 \frac{1}{r} = \frac{kZe^2}{r^2} \quad [\text{ from (i)}]$$

$$\Rightarrow \quad r = \frac{n^2h^2}{4\pi^2 mkZ\, e^2}$$

For hydrogen, Z = 1

$$\therefore \quad r = \frac{n^2 h^2}{4\pi^2 m k e^2}$$

Numerical : $E_1 = -13{\cdot}6$ eV, $E_2 = -3{\cdot}4$ eV, $h = 6{\cdot}6 \times 10^{-34}$ Js

$E_2 - E_1 = h\nu$

$$\Rightarrow \quad \nu = \frac{E_2 - E_1}{h} = \frac{(-3{\cdot}4 + 13{\cdot}6) \times 1{\cdot}6 \times 10^{-19}}{6{\cdot}6 \times 10^{-34}}$$

$$= \frac{10{\cdot}2 \times 1{\cdot}6 \times 10^{-19}}{6{\cdot}6 \times 10^{-34}} = \mathbf{2{\cdot}47 \times 10^{15}\ Hz.}$$

SET II — 2001 (OUTSIDE DELHI)

Time allowed : 3 hours **Max. Marks : 70**

General Instructions :

Same as Delhi Board Set — I, 2001.

Note : Except for the following questions, all the remaining questions have been answered in Set — I.

Q. 4. Two stars with magnitudes m_1 and m_2 have values of their brightness l_1 and l_2 respectively. Write expression for $\frac{l_1}{l_2}$. **(1)**

Ans. $\frac{l_1}{l_2} = 100^{\frac{m_2 - m_1}{5}}$

Q. 9. Draw a labelled ray diagram of an astronomical telescope used in the normal adjustment position. State the expression for its magnifying power. **(2)**

Ans. The ray diagram is shown below.

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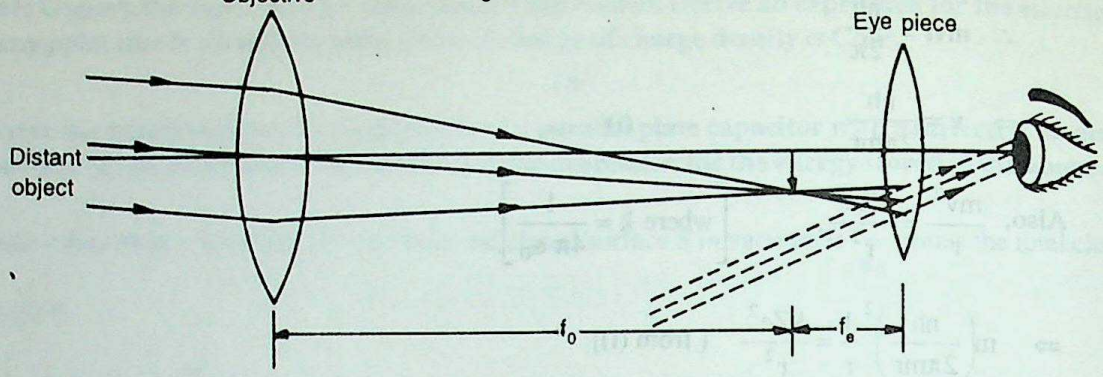

Magnifying power, $m = \frac{f_0}{f_e}$.

Q. 14. If the output of a 2-input NOR gate is fed as the input to a NOT gate (i) name the new logic gate obtained and (ii) write down its truth table. (2)

Ans. (i) The logic gate obtained is OR gate.

(ii) Truth table

A	B	$Y = \overline{A+B}$	$Y' = \overline{Y}$
0	0	1	0
0	1	0	1
1	0	0	1
1	1	0	1

Q. 21. Where should an object be placed from a converging lens of focal length 10 cm, so as to obtain a virtual image of magnification 2 ? (3)

Ans. $f = 10$ cm, $m = 2$

$$m = \frac{f}{f-u} \quad \Rightarrow \quad 2 = \frac{10}{10-u}$$

$$\Rightarrow \quad 10 = 20 - 2u$$

$$\Rightarrow \quad 2u = 10 \quad \Rightarrow \quad u = 5 \text{ cm}.$$

Q. 25. A charged particle of mass 'm', charge 'q', moving at uniform velocity 'v', enters a uniform magnetic field 'B' acting normal to the plane of the paper. Deduce expressions for the (i) radius of the circular path in which it travels, (ii) kinetic energy of the particle (assuming v << c). Why does the kinetic energy of the charge not change, when moving through the magnetic field ? (3)

Ans. (i) See answer to question 22, (outside Delhi) Set — I, 2001.

(ii) $$\text{K.E.} = = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{qBr}{m}\right)^2 = \frac{1}{2}\frac{B^2q^2r^2}{m}$$

Q. 26. How can a moving coil galvanometer be converted into a voltmeter ? To increase the current sensitivity of a moving coil galvanometer by 50%, its resistance is increased so that the new resistance becomes twice its initial resistance. By what factor does its voltage sensitivity change ? (3)

Ans. A moving coil galvanometer can be converted into a voltmeter by connecting a high resistance in series with the galvanometer.

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Voltage sensitivity, $V_s = \frac{I_s}{R}$

New current sensitivity $I'_s = \frac{150\, I_s}{100} = \frac{3I_s}{2}$

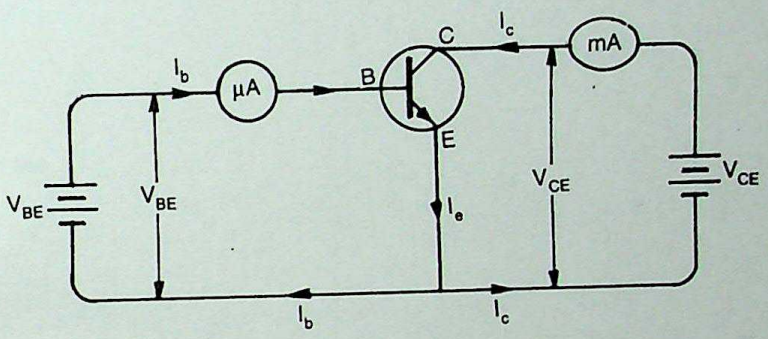
New resistance, $R' = 2R$

$\therefore$ New voltage sensitivity $V'_s = \frac{I'_s}{R'} = \frac{3I_s}{2 \times 2R} = \frac{3I_s}{4R}$.

$\therefore \quad \frac{V'_s}{V_s} = \frac{3}{4} \quad \Rightarrow \quad V'_s = \frac{3}{4} V_s$.

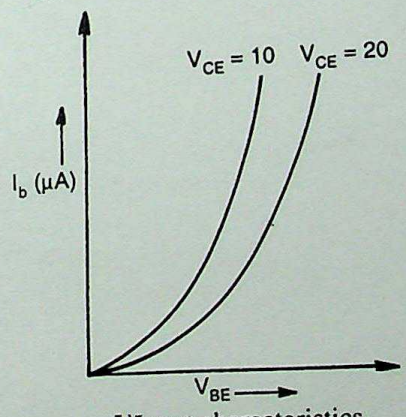
Q. 27. Draw a circuit diagram to obtain the characteristics of a n-p-n transistor in emitter configuration. Describe how you will obtain input and output characteristics. Give shape of the curves. **(3)**

Ans.

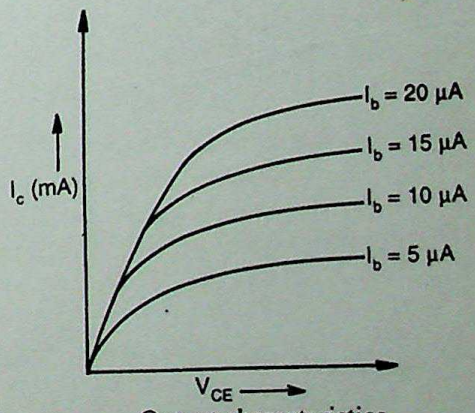


The input characteristics of the transistor represents the variation of the base current I_b with base emitter voltage V_{BE}, provided V_{CE} is fixed.

The output characteristics of the transistor represent the variation of collector current I_c with collector emitter voltage V_{CE}, provided I_b is fixed.



VInput characteristics



Output characteristics

SET III — 2001 (OUTSIDE DELHI)

All the questions have been answered in Set I and Set II.

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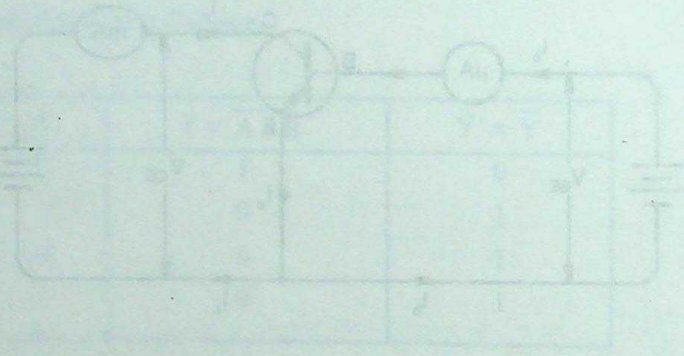

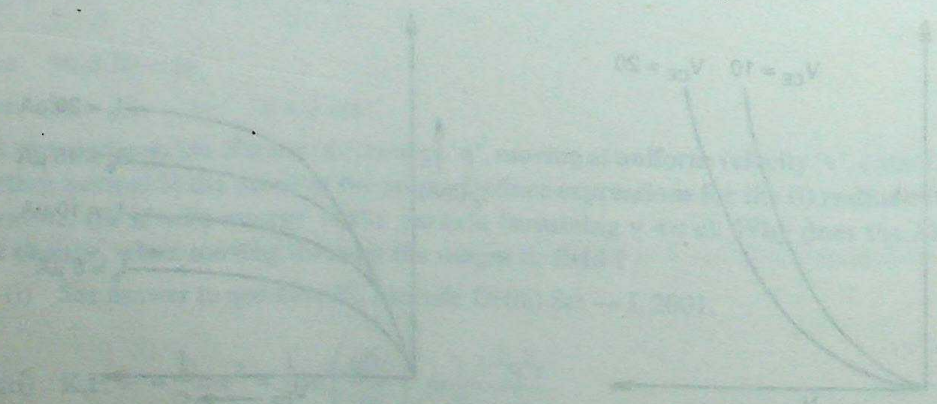

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